
Are Adults with Hearing Loss also at Risk of Attention and Memory Challenges, and can Hearing Loss Intervention Improve these Cognitive Areas?

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Abstract

Background: This study investigated the relationship between hearing loss and cognitive decline, and the use of hearing aids as a possible method to potentially combat cognitive aging in a New Zealand cohort. The aims of the study were: 1. Determine if individuals with hearing loss are at risk for selective attention and working memory cognitive deficits. 2. Determine if a 3-week trial of amplification was sufficient to improve, or be likely to arrest, aspects of hearing loss-related cognitive decline particularly, selective attention and working memory.

Methods: Selective attention and working memory abilities were measured in an experimental group before and 3 weeks after hearing aid fitting (n=8), a control group with hearing loss (n=27) and a normal hearing group (n=10). Experimental group participants were also administered two, subjective self-assessment, questionnaire-based tools before and after fitting, to survey perceived hearing handicap and aid benefit: the Abbreviated Profile of Hearing Aid Benefit (APHAB) and the Hearing Handicap Inventory for Adults (HHIA).

Results: There were significant relationships observed between auditory selective attention task measures and four frequency pure-tone average of both the left and right ear ($p < 0.01$) suggesting a relationship between hearing loss severity and attention measures. The experimental group participants showed some improvements in both measures of reaction time before and after hearing aid fitting compared to both a control and normal hearing group, although this did not reach statistical significance.

Conclusions: This study showed that hearing loss severity appeared to be related to cognition, with the experimental group who underwent a trial of amplification, showing small, but not significant improvements on measures of the auditory selective attention. The size of the experimental group limits conclusions but the results agree with other findings supporting a relationship between cognitive decline and hearing loss (Lin, 2011), and hearing aids as a means to facilitate the reduction of hearing loss-related cognitive deficits (Dalton et al., 2003; Mulrow et al., 1990). Outcomes from these investigations and the current study may lead to increased uptake of hearing aids at an earlier stage, following clinical diagnosis of aidable hearing loss. Together, these findings suggest

amplification plays a role towards potentially influencing the advance of cognitive aging – in addition to its established, positive impact on social isolation, communication difficulties, and related emotional hardships – likely improving the quality of life for the growing population of older adults with hearing impairment (Ciorba, Bianchini, Pelucchi, & Pastore, 2012).

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List of Abbreviations

4PTA	Four Frequency Pure-Tone Average
ANOVA	Analysis of Variance
APHAB	Abbreviated Profile of Hearing Aid Benefit
APT	Attention Process Training
ASA	Auditory Scene Analysis
ASA Task	Auditory Selective Attention Task
AT	Auditory Training
BE	Better Ear
BTE	Behind-the-Ear
CG	Control Group
dB HL	Decibel Hearing Level
DS	Digit Span
EG	Experimental Group
FM	Frequency Modulation
GDS	Geriatric Depression Scale
HA	Hearing Aid(s)
HHIA	Hearing Handicap Inventory for Adults
HHIE	Hearing Handicap Inventory for the Elderly
HI	Hearing Impaired
HL	Hearing Loss
Hz/kHz	Hertz/Kilohertz
LE	Left Ear

MMSE	Mini Mental State Examination
MWU	Mann-Whitney U Test
NAL-NL2	National Acoustic Laboratories, Non-Linear Version 2
NH	Normal Hearing
NIHL	Noise-Induced Hearing Loss
PPT	Participant
PTA	Pure-Tone Average
RE	Right Ear
REA	Right Ear Advantage
RITE	Receiver-in-the-Ear
RT	Reaction Time
RTD	Reaction Time Digit
SD	Standard Deviation
SPMSW	Short Portable Mental Status Questionnaire
SQQ	Speech, Spatial and Qualities of Hearing Scale
WE	Worse Ear

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1 Introduction

As every individual gets older, the normally aging brain will lose some of its ability to function as quickly or as easily as before, in a process known as cognitive aging (Park, 2000; Salthouse, 1996, 2009). The regions which are the earliest to be affected by age-related brain changes are the frontal lobe functions (Raz, 2000). The frontal lobes of the brain are involved in many important processes, specifically executive functions, memory, language, attention, and control of personality (Chayer & Freedman, 2001). Cognitive aging and elements of cognitive decline have been demonstrated in adults from as early as the 2nd and 3rd decade of life, for some individuals (Der & Deary, 2006; Salthouse, 2009).

A large proportion of older adults experience age-related hearing loss or presbycusis due to the deterioration of the peripheral, auditory sensory structures (Lessard-Beaudoin, Laroche, Demers, Grenier, & Graham, 2015). There are also a large number of individuals who experience noise-induced hearing loss, due to noise exposure. This is potentially influenced by a lack of preventive, early education about the effects of prolonged or intense noise exposure on the hearing system and corresponding hearing acuity (John, Grynevych, Welch, McBride, & Thorne, 2014). Unsurprisingly, hearing loss reduces the ability of the individual to hear, but it also makes it more difficult for people to discriminate separate noise or sound sources, making it particularly difficult for people with hearing loss to hear in background noise (Bayat et al., 2013). Additional social and emotional effects of hearing loss include social isolation (Mick, Kawachi, & Lin, 2014), anxiety between spouses or life partners (Héту, Riverin, Lalande, Getty, & St-Cyr, 1988); and decreased quality of life (Ciorba et al., 2012; Dalton et al., 2003).

The focus of the research study presented was the relationship between hearing loss and cognitive decline. Older people who have measurable hearing loss have been shown to experience more significant cognitive decline, compared to normal hearing peers (Lin et al., 2013; Valentijn et al., 2005). Hearing loss severity can affect the magnitude of cognitive decline experienced, with

greater hearing loss associated with lower scores on tests of executive function and psychomotor processing (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011).

Hearing aids are a way to treat hearing loss, with a primary aim being to restore peripheral sensory input as much possible, given aid technology and residual hearing (Golabek, Nowakowska, Siwiec, & Stephens, 1988). Studies surrounding the use of hearing aids and cognitive decline are emerging, although hearing aids have been shown to have significant benefits in other areas, such as social interaction, general life impact and physical health (Mulrow et al., 1990; Öberg, Marcusson, Nägga, & Wressle, 2012; Tsakiropoulou, Konstantinidis, Vital, Konstantinidou, & Kotsani, 2007). However, a small number of previous studies do exist, demonstrating that hearing aids have been shown to improve cognition in a wide variety of perceptual domains including: orientation, short-term memory, attention, language, motor function, and perception (Acar, Yurekli, Babademez, Karabulut, & Karasen, 2010; Choi, Shim, Lee, Yoon, & Joo, 2011; Mulrow et al., 1990) and reduce scores on depression scales (Acar et al., 2010; Cacciatore et al., 1999). Conversely, certain earlier studies have shown that hearing aids have no preventative effect on cognitive decline (Allen et al., 2003; van Hooren et al., 2005). It is unclear whether this lack of consensus regarding amplification and cognition was impacted by the hearing aid model used or the study design; with some studies measuring outcomes on multiple occasions over months, while others only measured once at the end of the fitting process. In a recent study, hearing aid use was associated with better cognition, although the authors were unsure if this was due to self-efficacy improvements (Dawes et al., 2015). A systematic review noted hearing aids can impact immediate short-term cognitive outcomes, although the long-term effects were unknown (Kalluri & Humes, 2012).

Thanks to improved medicine and nutrition resulting in longer lifespans, there is an increasing demand to study cognitive aging (Ciorba et al., 2012). People are living and working longer, resulting in the need to be mentally proficient for as long as possible to ensure that quality of life, personal and economic, are maintained (Butler, Forette, & Greengross, 2004; Dini & Goldring, 2008). If hearing aids could be used as a means of treating cognitive decline, there could potentially be significant individual and societal benefits. The outcome of such studies may possibly promote increased uptake of hearing aids from an earlier stage, following an individual's hearing loss diagnosis. Timely

intervention towards addressing aidable hearing loss may have the ancillary benefit of possibly slowing cognitive aging. For the growing population of older adults with hearing impairment, amplification has been shown to help prevent: potential social isolation, reduce hearing loss-related communication difficulties leading to emotional hardships, and improve the overall quality of life (Mulrow et al., 1990). There is a clear need to further examine the relationship between rehabilitative strategies, such as hearing aids and cognition, in older participants with hearing loss (Dawes et al., 2015; Kalluri & Humes, 2012; Lin et al., 2013).

2 Literature Review

2.1 Cognitive Aging

2.1.1 Introduction

As a person ages, it is unavoidable that every individual will experience some deterioration of central systems (Salthouse, 2009). The aging brain may exhibit a loss of some of its ability to function as well as one may like, and as such, may result in difficulty with performing tasks as quickly or easily as one may have in the past (Salthouse, 1996). This inability to perform tasks as accurately or quickly is called cognitive aging - measurable deficits in mental performance associated with advancing age (Park, 2000). It should be noted that this is a separate issue from mild cognitive impairment (e.g., concentration deficits) or any form of dementia. Thanks to improved medicine and nutrition, there is an increasing demand to study cognitive aging as people are living and working longer, resulting in the need to be mentally proficient for as long as possible to ensure that quality of life and societal interactions and contributions are preserved (Butler et al., 2004). This section aims to discuss why all individuals will experience some form of cognitive aging (if they reach an applicable age for this to conceivably occur), the physiology behind this, the cognitive processes which are affected, and studies which focus on cognitive decline.

2.1.2 Physiology

Deterioration in subjective or functional ability has been linked to changes in the grey and white matter of the brain (Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003). Specifically, as we age, brain tissue size decreases and cerebrospinal fluid volume increases (Coffey et al., 2001). This results in diminished brain activity in certain regions, which causes cognitive decline in specific functions (Grady, 2008). These physiological changes manifest as a range or variety of limitations in

cognitive proficiency, appearing to occur on a continuum due to the influence of individual and environment factors (Grady, 2008).

The regions which are the earliest to be affected by age-related brain changes are the frontal lobe functions (Raz, 2000). The frontal lobes of the brain are involved in many important processes, specifically executive functions, or those principle regulating functions that manage or control cognition (Raz, 2000). These functions include: memory, language, attention, and maintenance of personality or individual character (Chayer & Freedman, 2001). Cognitive aging and elements of cognitive decline has been identified at early ages for some adults, detected when they are in their 2nd and 3rd decade of life (Der & Deary, 2006; Salthouse, 2009).

2.1.3 Affected Functions

2.1.3.1 Memory

Cognitive aging affects multiple functions, of which memory is perhaps the most well-studied. There are different aspects of memory, for example: working memory is the preservation of information while simultaneously processing some other piece of information (Salthouse & Babcock, 1991), explicit memory is remembering specific events (Craig & Grady, 2002) and procedural memory is that which reflects previously learned skills (Craig & Grady, 2002). Multiple studies have found all of these memory realms are affected by age (Bopp & Verhaeghen, 2005; Jennings & Jacoby, 1993; Kataria, 2014; Neidleman, Wambacq, Besing, Spitzer, & Koehnke, 2015).

Bopp and Verhaeghen (2005) found that when using varied methods of testing auditory “memory span”. In their study, two types of memory span were tested, “short-term memory span” and “working memory span”, with clear age differences seen using all methods and stimuli (words, letters, or numbers) (Bopp & Verhaeghen, 2005, p. 223). Short-term memory span is the recollection of presented auditory stimuli, be it numbers or words, in the order they were presented. Working memory refers to the manipulation of data which is being held in memory, for example, recollection of a sequence of numbers in backwards order (Bopp & Verhaeghen, 2005). Working memory tasks

showed more significant age effects than short-term memory span tasks, although both conditions showed age-related differences (Bopp & Verhaeghen, 2005).

Another study investigated the effect of background noise presented during working memory tasks, on younger participants compared to middle-aged participants (Neidleman et al., 2015). The rationale for conducting this study with middle-aged participants was to control for hearing status as a confounding factor, as age-related loss is more likely with older participants (Neidleman et al., 2015). However, even with the behavioural hearing ability of the middle-aged participants matched to the younger participants, background noise was significantly more detrimental for middle-aged participants; thus producing poorer explicit memory recall scores than that demonstrated by the younger participants (Neidleman et al., 2015).

Multiple memory domains experience varying degrees of deterioration with age (Bopp & Verhaeghen, 2005; Jennings & Jacoby, 1993; Kataria, 2014; Neidleman et al., 2015). Explicit memory, the conscious recollection of experiences, similarly declines with age (Kataria, 2014). Jennings and Jacoby (1993) found age differences in consciously-controlled memory processes when comparing 18-23 year olds with 66-90 year olds. Implicit memory is the use of past experiences for tasks which are not directed related to memory, for example, lexical identification (Kataria, 2014). Implicit memory is also affected, with participants between 30-50 years demonstrating better memory than those over 60 years old (Kataria, 2014).

Working memory is the particular aspect or domain of memory which this study focussed on. Working memory is defined as the process of holding something in memory, in order to change or manipulate this information (Salthouse & Babcock, 1991). It requires both processing and storage, which is why it is essential to many daily tasks (Salthouse & Babcock, 1991). There is a limit to working memory: working memory manipulations and task performance will decline with the increasing complexity of the task, as the working memory storage capacity has reached its limit (Oberauer, 2005). Tasks which measure maximum working memory capacity are often used to determine cognitive function and identify cognitive aging, as capacity is shown to decrease in older adults (Oberauer, 2005). An example of memory tasks is digit span, requiring participants to be presented with a sequence of digits, and asking them to listen to and recall those digits (Lumley &

Calhoun, 1934). The maximum number of digits able to be recalled correctly is the maximum span (Lumley & Calhoun, 1934).

The reason why older adults experience memory decline obviously has a physiological evidence base as supported by research (Charlton, Barrick, Lawes, Markus, & Morris, 2010; Wang et al., 2011). Age-related changes in memory domains have been linked to prefrontal cortex dysfunction (Wang et al., 2011). Prefrontal cortex neuron measurements in older monkeys show decreased firing compared with their younger peers during working memory tasks (Wang et al., 2011). Further, reduction in the white matter of the human brain has been shown to be associated with working memory decline (Charlton et al., 2010).

2.1.3.2 Attention

Attention has also been shown to decline with age (Commodari & Guarnera, 2008; Panek & Rush, 1981). Attention as a whole is important because it allows the brain to focus on what it needs to do. Without it, we would be unable to successfully complete any task (A. A. Hartley, 1992). A specific type of attention, selective attention, involves the participant concentrating on a perceptual event, often in the presence of other distractors (Coch, Sanders, & Neville, 2005; Madden & Whiting, 2004). It is sometimes called focussed attention (Kahneman, 1973). The source which needs to be attended-to can be visual (Brink & McDowd, 1999; Commodari & Guarnera, 2008) or auditory (Barr & Giambra, 1990; Commodari & Guarnera, 2008; Panek & Rush, 1981).

Visual attention tasks involve searching for a specific feature in the presence of other distractors, like looking for a blue circle among many other blue shapes. Older participants showed slower reaction times during an attention-shifting visual-spatial task (Commodari & Guarnera, 2008). The 'Colour-Word' task, which requires naming a colour of a presented word while ignoring the semantic meaning of the word (a colour name), was used in a study by Brink and McDowd (1999, p. 30). Their results showed older adults performed significantly worse than younger adults for this task (Brink & McDowd, 1999).

The particular aspect of attention and cognitive aging which this study focussed on was auditory selective attention. Specifically, auditory selective attention. It is the ability to focus on

something which the brain needs to focus on, in the presence of perceptual ‘objects’ which are competing for attention. The brain accomplishes this by grouping and segregating the perceptual input into separate ‘auditory streams’, using a concept called Auditory Scene Analysis (Bregman, 1990, p. 10). An ‘object’ is a sound which one is able to identify as a single source by the perception of its similar characteristics which separate it from other objects (Moore, 2013). Stated another way, auditory selective attention occurs when the brain focusses on a target signal, in the presence of distracting stimuli (e.g., background noise); similar to listening to a companion speaking while in a busy restaurant (Cherry, 1953). This is known as the “Cocktail Party Effect”, the ability to listen to a target sound while the brain filters out unwanted superfluous ‘other’ noise (Cherry, 1953, p. 975).

Several previous studies have looked at auditory selective attention and cognitive aging (Barr & Giambra, 1990; Commodari & Guarnera, 2008; Panek & Rush, 1981). Older research participants have been shown to have less selective attentional control than younger participants - resulting in diminished ability to ignore distractor-stimuli (Fabiani & Gratton, 2013). Commodari and Guarnera (2008) found an age-related reduction in some aspects of attention, which was significantly greater in 60-65 year olds compared to 55-59 year olds. Similarly, Panek and Rush (1981) found a significant decrement in selective attention when comparing across 3 distinct, participant age groups: younger 20-30 years, middle 40-50 years and older 60-70 years. Age-related differences were evident during a dichotic listening task. Humes, Lee, and Coughlin (2006) did not find a significant difference during a dichotic selective attention task for elderly hearing impaired users compared against a younger normal hearing control group. The task involved listening to a target speaker indicated by a visual call-sign cue, and selecting the appropriate colour and digit of the target speaker, in the presence of a competing speaker of a different sex who also presented a colour and a digit (Humes et al., 2006). This could be due to the relatively small sample size of younger ($n = 10$) and older ($n = 13$) participants (Humes et al., 2006). Additionally, the older participants completed prior cognitive screening tasks as part of their inclusion criteria, which meant their participants were capable with regards to those cognitive tasks indexed by the screening (Humes et al., 2006).

However, Barr and Giambra (1990) did identify selective attention deficits in older adults during a dichotic listening task, although they were unable to clearly identify the underlying cause.

They proposed that the difficulty either came from poor identification of the target sound, or an inability to ignore irrelevant non-target noise (Barr & Giambra, 1990). This is similar to the previously-mentioned theory that working memory performance is affected by the ability to inhibit irrelevant information (Hasher, Zacks, & May, 1999). Both weak target recognition and/or filtering of non-salient noise could be related to hearing loss (Barr & Giambra, 1990).

A possible reason explaining all of the aforementioned age-related effects has been attributed to reduction in processing speed with age (Salthouse, 1996). This was thought to result in poorer performance on cognitive tasks, including those of attention and working memory (Salthouse, 1996). This is in line with the idea that fluid intelligence, which is problem solving and reasoning, declines with age (Bugg, Zook, DeLosh, Davalos, & Davis, 2006). In contrast, crystallized intelligence, which encompasses vocabulary and general information learnt, remains reasonably stable as we age (Horn & Cattell, 1967). However, understanding the mechanisms underlying cognitive aging still requires further research and discussion (Salthouse, 2004).

2.2 Neural Plasticity

2.2.1 Introduction

Neural plasticity refers to the finding that the brain can change and rewire itself, especially through targeted development and training programs (Foster, 2015). Neural circuits have been shown to change in structure and function as the result of activity, which results in developments in efficacy and excitability (Zhang & Poo, 2010). Recent studies have focussed on the relationship between neural plasticity and aging, specifically whether training can prevent age-related decline in mental functions such as memory, attention, processing speed, and reasoning (Foster, 2015).

Neural plasticity allows the human brain to be altered and developed due to environmental stimulation (Zhang & Poo, 2010). This plasticity is essential for new-borns being exposed to the world, as their brain is still in a stage of early development (Kolb & Gibb, 2011). Although neural plasticity is related to age, it has recently been shown to continue well into adult years (Boyke, Driemeyer, Gaser, Büchel, & May, 2008). This allows humans to learn and develop, even into old

age, through cognitive stimulation and training (Boyke et al., 2008). The following section discusses cognitive training – that is, intervention programs which aim to improve task performance following targeted training. This is only possible due to the fact that neural plasticity exists in adults (Boyke et al., 2008). Cognitive training methods involving memory and attention studies will be examined, with the aim of investigating the claim that memory and attention abilities can be improved.

2.2.2 Cognitive Training

In recent research, studies have supported the use of intervention programs to possibly slow or arrest the cognitive aging process by using ‘cognitive training’ (Ball et al., 2002, p. 2272; Suzuki et al., 2014). Cognitive training generally focusses on improving a particular cognitive aspect, such as memory or attention, using repeated teaching via a set program or design (Clare & Woods, 2004). Cognitive training is an application of the theory that neural plasticity – the ability of the brain to change through learning or experiences – continues throughout adulthood (Recanzone, 2000). The Hebbian theory of synaptic plasticity attempts to explain this phenomenon (Hebb, 1949). As one cell fires, it causes another cell to fire, promoting neural growth and development (Hebb, 1949). Thus, the connection and strength of the two cells increases. This theory explains why the brain is able to develop through the use of cognitive training programs.

Cognitive training programs have been found to be beneficial in multiple populations and subgroups apart from the elderly (Ball et al., 2002; Suzuki et al., 2014; Wolinsky, Weg, Howren, Jones, & Dotson, 2013). Other populations benefitting from the use of cognitive training include those with Alzheimer’s disease (Clare & Woods, 2004), those with brain injuries (Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000), and those with schizophrenia (Twarnley, Jeste, & Bellack, 2003).

The application and use of targeted training programs via randomised controlled trials have found improvements in older participants in executive functions such as: memory (Ball et al., 2002; Suzuki et al., 2014), reasoning (Ball et al., 2002), and visual processing (Wolinsky et al., 2013). Further, these intervention effects have been shown to still be significant 10 years after the intervention ended (Rebok et al., 2014). These effects were seen after ten 60- to 75-minute sessions over 5 to 6 weeks, with four additional booster training sessions at 11 and 36 months (Rebok et al.,

2014). The following section aims to discuss previous methods used in cognitive training, and the results of the application of these methods, to different targeted cognitive functions.

To effectively deliver cognitive training, several methods have been attempted involving different cognitive domains. Examples of styles used to provide cognitive training involve: traditional instructor-focussed exercises (Rebok, Carlson, & Langbaum, 2007), regulated classroom programs (Aguirre, Woods, Spector, & Orrell, 2013), and more recently due to technology developments, computerised games (Karch, 2014; Kueider, Parisi, Gross, & Rebok, 2012).

Cochlear implants may be seen as a method of cognitive training, by providing auditory input for people with severe hearing losses adjunct to listening exercises (Fallon, Irvine, & Shepherd, 2002). A tiny device is surgically inserted into the patient's cochlea, i.e. their organ of hearing, in order to provide electrical stimulation using multiple electrodes. This stimulates the auditory nerve and the involved neural sites (Fallon et al., 2002). The central auditory system has proven to be extremely plastic, as demonstrated by adults who become successful users of cochlea implants (Fallon et al., 2002). Further, people with cochlea implants have been shown to have continued improvements in speech perception, after using their implant for some time (Fallon et al., 2002). Cochlear implants are being seen as a tool which provides neural stimulation, together with training and therapy which may facilitate neural plasticity, and therefore thought to promote meaningful hearing experience post-implant (Mauldin, 2014). Such findings support indications that the central auditory system is able to develop and change, given the appropriate conditions, such as input modality combined with training.

2.2.3 Previous Studies of Cognitive Training

This section aims to discuss previous studies and research involving cognitive training, to determine whether there is support for memory and attention task performance improving via intervention – in this case, cognitive training. The population this project targeted was older participants with hearing loss. The specific cognitive functions investigated and treated through the use of cognitive training (active listening supported by hearing aid use) were working memory and auditory selective attention. Within this section, relevant studies involving memory, studies involving

attention, and studies involving participants with hearing loss are detailed. Studies involving older participants with hearing loss, the targeted population of this research, will be discussed more fully in Section 2.5.3. Although the focus of the current project involved older participants, other relevant research is also presented.

2.2.3.1 Studies Involving Memory

The working memory centre of the brain is situated in the frontal and parietal cortex and basal ganglia (Klingberg, 2010). These areas have been shown to decline in activity during working memory tasks in older participants (Klingberg, 2010) yet increase in activity following working memory training (Olesen, Westerberg, & Klingberg, 2004; Westerberg & Klingberg, 2007). These physiological correlates of working memory training are evidence that neural plasticity occurs in the centres of the brain which control working memory capabilities.

Cognitive training focussing on memory in older participants has undergone much research (Eckroth-Bucher & Siberski, 2009; Rebok, Rasmusson, & Brandt, 1996; G. E. Smith et al., 2009; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2012). A study by Eckroth-Bucher and Siberski (2009) conducted a randomised controlled trial involving 32 participants over the age of 65, with varying degrees of cognitive impairment. Cognitive training involved 45 minutes a day of traditional and computerised programs, twice a week for six weeks. Results showed significant improvements on the Dementia Rating Scale (Mattis, 1988) scores, for those who were mildly or moderately impaired in tests of memory (Eckroth-Bucher & Siberski, 2009). Another study involving participants without significant cognitive impairment utilised a computerised training program for one hour per day, five times a week for 8 weeks. Researchers reported improved memory among their participants (G. E. Smith et al., 2009). An older, smaller study using a computerised battery of tasks found significant improvement within and across training sessions for implicit and explicit memory, involving only 1.5 hours per week for 9 weeks (Rebok et al., 1996).

For elderly individuals over 80 years, working memory training programs have also been beneficial (Zinke et al., 2012). A training group with a mean age of 86.8 years showed significantly greater gains in working memory abilities than a control group, following 5 working memory tasks

trained over 10 sessions (Zinke et al., 2012). However, there were no observable transfer or generalizable effects which led the authors to discuss the limitations of the study; such as the small sample size and the relatively low number of training sessions (Zinke et al., 2012). A study comparing older participants (70-80 years old) with younger counterparts (20-30 years old) who underwent working memory training, showed both groups experienced substantial performance gains following training for 15 minutes per day for 45 days (Li et al., 2008). Unlike the study by Zinke et al. (2012), Li et al. (2008) also found improved results in a similar non-trained task, i.e., a transfer effect. These findings support the theory of neural plasticity and the application of cognitive training with older adults, at least regarding the function of working memory.

2.2.3.2 Studies Involving Attention

The use of a specialised Attention Process Training program has shown cognitive improvements in patients and research participants (López-Luengo & Vázquez, 2003; Palmese & Raskin, 2000; Sohlberg & Mateer, 1987; Sohlberg et al., 2000). Attention Process Training (APT) is a program initially designed to remedy attentional deficits reported and demonstrated by people with closed-head, brain injury (Sohlberg & Mateer, 1987). It trains several different attention domains including: selective, divided, alternating, and sustained attention (López-Luengo & Vázquez, 2003; Sohlberg & Mateer, 1987). The tasks involved in the program increase in complexity as the participant becomes more able (Sohlberg & Mateer, 1987). Sohlberg and Mateer (1987) originally demonstrated the effectiveness of APT in brain-injured persons. They documented improvements across 4 participants in their preliminary study following intensive cognitive remediation, including 5 to 10 weeks of specific attention training, based on interview and assessment (Sohlberg & Mateer, 1987).

A study involving people with acquired brain injuries showed improvements in working memory and attention following 10 weeks of APT (Sohlberg et al., 2000). Similarly, Palmese and Raskin (2000) showed improved attention and task-based performance speed for participants with mild traumatic brain injuries following APT use for 10 weeks. These improvements remained stable for at least 6 weeks following the conclusion of the program. A project by López-Luengo and

Vázquez (2003) involving participants with schizophrenia who completed the APT programme, resulted in significantly higher performance on executive function than a control group. These findings appear to support that attention can be improved through training, as can working memory and reasoning (Ball et al., 2002; Wolinsky et al., 2013).

In older participants, as mentioned earlier, it is thought that age-related deficits in attention are possibly related to a reduced ability to ignore or filter out irrelevant distractors and focus on the target signal (Barr & Giambra, 1990). However, results involving this population and training-related attentional improvements are encouraging. In the aforementioned study from G. E. Smith et al. (2009), the authors reported improved attention following completion of their program which lasted for 8 weeks of computerised cognitive training. Mozolic, Long, Morgan, Rawley-Payne, and Laurienti (2011) used a modality-specific attention training program lasting 1 hour per week for 8 weeks. The experimental group showed significant improvements over the control group in selective attention; both auditory and visual (Mozolic et al., 2011). Behavioural-related improvements and also objective electrophysiological enhancement has been evident in the aging brain, following cognitive training (O'Brien et al., 2013).

2.2.3.3 Studies Involving Hearing Impairment

People who have hearing loss have also been known to undergo cognitive training, often called Auditory Training (AT), as a means to improve speech perception (Kricos & McCarthy, 2007). A systematic review of AT studies revealed intervention has been shown to be successful in the management of some adults with hearing loss (Sweetow & Palmer, 2005). The intervention strategy of the majority of these studies involved 7-8 hours of training spread over 2-4 weeks. Despite the positive findings of such studies, time restraints and limited financial gain for private practices has restricted the inclusion of AT for adults acquiring hearing aids (Anderson & Kraus, 2013).

The rationale for the study of people with hearing loss is based on findings suggesting the brains of people with sensorineural hearing loss are less able to accurately and efficiently transmit perceptual information (Lunner, Rudner, & Rönnberg, 2009). Additionally, older participants with hearing loss are shown to have accelerated cognitive decline in other areas such as memory and

attention which could potentially benefit from cognitive training (Lin et al., 2013). This will be discussed more fully later in the literature review (see Section 2.5).

2.3 Hearing Loss

2.3.1 Anatomy and Physiology of the Ear

A brief overview of the anatomy and physiology of the ear will be covered to explain normal auditory function. For in-depth coverage and further detail, readers may wish to refer to textbooks by Moffett, Moffett and Schauf (1993); Perkins and Kent (1986); and Seikel, King, and Drumright (2010).

The ear is divided into four parts: the outer ear; the middle ear; the inner ear; and the auditory nerve (Moffett, Moffett, & Schauf, 1993). Each part plays an important role in the conduction of sound, allowing vibrations propagating through air to become meaningful speech and sounds received and processed by the brain (Moffett et al., 1993).

The sound vibration propagates through the air towards the outer ear, which consists of the pinna, the visible part of the ear (Seikel, King, & Drumright, 2010). The shape of the pinna aids humans in our ability to locate sound, especially sounds in the speech frequency range (Seikel et al., 2010). Upon entering the ear, the sound is amplified by the resonance of the ear canal, the external auditory meatus (Seikel et al., 2010). At the end of the external auditory meatus is the tympanic membrane, commonly known as the ear drum, and the beginning of the middle ear portion of the peripheral hearing system (Moffett et al., 1993). The purpose of the middle ear is to match the impedance of the incoming sound signal arriving via air conduction, to the fluid environment of the inner ear (Moffett et al., 1993).

The ear drum has the first of a chain of three tiny bones embedded on its medial surface (Moffett et al., 1993). Collectively these bones are known as the middle ear ossicles, and form the connection across the middle ear linking the tympanic membrane and the cochlea, or the auditory section of the inner ear (Moffett et al., 1993). The first bone is the malleus, which is embedded in the

tympanic membrane at one end, and attached to the incus, the second ossicle at the other/medial end. The incus joins to the stapes, the tiniest ossicle (Seikel et al., 2010). As the ear drum vibrates due to the vibrations of the sound, the ossicles also move (Seikel et al., 2010). Due to the size difference between the tympanic membrane and oval window, there is an increase in the pressure which will be exerted on the inner ear, therefore overcoming the resistance to the flow of energy, the impedance represented by its fluid interior (Seikel et al., 2010). The coupling between the middle ear and the inner ear is through the smallest bone in the body, the stapes. The stapes is located between the incus and the entrance to the inner ear, the oval window (Moffett et al., 1993).

The heightened force introduced by the middle ear enters the auditory section of the inner ear and the spiral-shaped cochlea (Moffett et al., 1993). Apart from the auditory section, the inner ear also contains the vestibular system which is for balance (Perkins & Kent, 1986). The cochlea's fluid core is partitioned into 3 sections, with the middle division containing the Organ of Corti, the organ of hearing. The incoming vibrations cause the fluid to move in a certain way, which is specific to that sound's characteristics. The corresponding movement of the fluid causes the Organ of Corti to respond (Moffett et al., 1993). The Organ of Corti is arranged tonotopically, with high frequencies located near the entrance to the cochlea and low frequencies located deeper – in the centre of the spiral. High frequency sounds produce shorter waveforms, while low frequency sounds produce longer waveforms (Seikel et al., 2010).

The Organ of Corti contains thousands of sensory hair cells which move together when the Organ of Corti is activated by sound energy, and change the corresponding mechanical movement into electrical impulses in response to incoming stimulation (Seikel et al., 2010). These impulses cause the primary auditory neurons to fire, which are then transmitted along the final part of the peripheral hearing system, the auditory nerve (Seikel et al., 2010). The auditory nerve is the beginning of the connection between the ear and the brain (Moffett et al., 1993). Once the sound reaches the brain via the auditory nerve and travels through a complex network of auditory pathways and nuclei, the brain processes the incoming information which enables us to know which sound is being heard (Seikel et al., 2010). For a human to be able to hear sounds like speech well, all sections of this pathway need to be working and undamaged (Moffett et al., 1993).

2.3.2 Introduction to Hearing Loss

Hearing loss is the third most common chronic health condition for older adults (Cruickshanks et al., 1998). A previous study reported the prevalence of hearing loss for people between 48-92 years old to be 45.9% (Cruickshanks et al., 1998). Another study found that in adults over 70 years old, the prevalence was 63.1% (Lin, 2011). Loss of auditory sensory function in older adults can seriously affect their ability to work and their quality of life; hindering their well-being and ultimately, their social and economic communities (Ciorba et al., 2012; Dalton et al., 2003). Further, more recent research has linked hearing loss to accelerated cognitive decline (Lin, 2011; Lin et al., 2013). This section will detail the two most common causes of later-life acquired hearing loss – i.e. presbycusis and noise-induced hearing loss – the physiology of hearing loss, the potential effects of hearing loss on the individual, and the efficacy and use of some current treatments available for people with hearing loss.

2.3.3 Causes

There are two common causes of hearing loss which will be discussed: presbycusis and noise-induced hearing loss. These two conditions are very common causes of gradual, acquired adult hearing loss. Often an individual's hearing loss will be attributed to both noise and age, as it is difficult to separate natural deterioration from environmental factors (Liu & Yan, 2007).

2.3.3.1 Noise-Induced Hearing Loss

A cause of hearing loss which is seen very commonly in the aging population is noise-induced hearing loss. Noise-induced hearing loss (NIHL) is deterioration in hearing due to exposure to noise at a level which is damaging to the inner ear (Nair, 2014). The damage can be produced by ongoing exposure to noise, or by a sudden very loud sound which can cause permanent damage to the

inner ear and thus, hearing loss (McReynolds, 2005). The typical audiometric configuration for NIHL is a “notch” centred near 4 kHz on an audiogram (McBride & Williams, 2001).

People who experience NIHL have often been exposed to this noise through their workplaces, known as occupational noise exposure (John et al., 2014). In New Zealand, examples of industries where noise has been measured to be a high level include: agriculture, mining, construction and manufacturing (John et al., 2014). Between 1995 and 2005, over 44,000 new claims to Accident Compensation Corporation for NIHL were made, resulting in a cost of over \$193.82 million in this time period (Thorne et al., 2008).

For the cohort this project focussed on, it was anticipated that some participants would have some degree of both NIHL and presbycusis. Evidence of NIHL was considered likely due to limited preventative or governmental strategies in place in New Zealand, over the past 35 years. Prior to 1981, there was no relevant legislation detailing occupational NIHL prevention in New Zealand (Laird et al., 2011). The Factories and Commercial Premises Act (1981) specifically mentioned noise, although prevention was not explained thoroughly (Laird et al., 2011). It wasn't until 1996 that the Approved Code of Practice for the Management of Noise in the Workplace was published, which has since been updated (Department of Labour, 1996). This was organised by the Occupational Health and Safety Service to prevent future generations of New Zealanders from potential exposure to noise, sufficient to cause NIHL. It describes how to assess noise levels, control noise levels, monitor hearing status of workers and the duties staff are required perform, in order to prevent hearing deterioration due to workplace conditions (Department of Labour, 2002).

2.3.3.2 *Presbycusis*

Peripheral sensory structures experience deterioration with age (Lessard-Beaudoin et al., 2015). Age-related hearing loss, or presbycusis, has been studied considerably, due to the growing aging sector of the population (Ciorba et al., 2012). Thanks to improved nutrition and medicine, people are living longer and staying active longer (Dini & Goldring, 2008). However, difficulties in communication can hinder quality of life for the elderly (Ciorba et al., 2012).

Hearing acuity decreases with age because of changes in the inner ear, in particular, deterioration within the cochlea or organ of hearing. The aging cochlea experiences loss of the hair cells and sensory receptors, which reduces the ability of an individual to hear well (Ko, 2010). The affected cells are most often the ones nearest the entrance to the cochlea, the basal end, which encodes high-frequency sound information (Gates & Mills, 2005). If the damaged range progresses and affects the hair cells encoding the mid-frequencies, speech becomes increasingly difficult to hear or understand (Gates & Mills, 2005).

Presbycusis can significantly affect people from as early as 40 years old (Arvin, Prepageran, & Raman, 2011). Data shows the likelihood of having a more severe hearing loss with increasing age (Glorig & Roberts, 1965). The odds of having hearing loss are higher for men than women, which may be expected considering work-related NIHL (Cruickshanks et al., 1998), and more likely for Caucasians than Hispanic or Black ethnic groups (Lin et al., 2011). A recent study found women were more prone to have a ‘flat’ audiogram configuration, indicating all frequencies or pitches are similarly affected, while men were more likely to have a ‘high-frequency steeply-sloping’ configuration (Demeester et al., 2009). The authors thought that these differences between the configuration of hearing loss for men and women could be hormonal (for women), relating to the important role of oestrogen within the stria vascularis. Oestrogen interactions within the inner ear were also observed in previous studies, which demonstrated the role of oestrogen as a ligand for megalin, a protein which is essential for hearing, in the cells of the stria vascularis (König et al., 2008; Simonoska et al., 2009).

Typically, presbycusis is able to be classified into one of four types: sensory, neural, metabolic or mechanical. These types describe the pathological origins of the hearing loss, and present with four different, typical audiograms. This was originally documented by Schuknecht (1964). Schuknecht’s work is considered the foundation for much of the research on the causes and definitions of presbycusis.

Sensory presbycusis is caused by the deterioration of the Organ of Corti (Schuknecht, 1964). Deterioration begins in the basal end of the cochlea, i.e. the high frequencies, and progresses slowly towards the apical end, i.e. the low frequencies, affecting both ears (Connelly, 2003). This type of slow degeneration may begin as early as childhood, although significant, measurable hearing loss may

not be noted until middle or old age (Connelly, 2003). Schuknecht et al. (1974) suggested that the cause could be decreased enzyme activity which results in cell loss for the auditory neurons of the organ of Corti. A typical clinical finding for a person with sensory presbycusis reveals a sharply sloping high-frequency bilateral hearing loss. The lower speech frequency range, i.e. 500 – 2000 Hz, would have hearing thresholds consistent with more normal hearing sensitivity.

In comparison, neural presbycusis is known to affect the speech frequency range to a greater degree (Gacek & Schuknecht, 1969). This is due to the involved auditory neurons being affected by degeneration, not just those in the organ of Corti, as with sensory presbycusis (Connelly, 2003). However, the basal end of the cochlea is typically, slightly more affected than the apical end (Gacek & Schuknecht, 1969). This means the affected nerve cells also generate follow-on consequences which include the central neural pathways. The degeneration of the entire auditory pathway reduces speech discrimination due to the reduced number of functioning neurons (Connelly, 2003). Pure-tone audiometry assessment may be consistent with a similar degree of loss to that of sensory presbycusis, but monaural speech discrimination scores are often worse than expected (Connelly, 2003).

Metabolic or stria presbycusis is the third classification of presbycusis. The underlying cause is the atrophy of the stria vascularis, which is responsible for the chemical and bioelectric balance and health of the endolymph in the cochlea (Schuknecht et al., 1974). Together with perilymph, endolymph maintains the electrochemical properties of the inner ear hair cells. Hair cells along the entire Organ of Corti are affected (Gacek & Schuknecht, 1969), resulting in a flat-configuration sensorineural hearing loss. Patients with metabolic presbycusis tend to have good speech discrimination scores at elevated presentation levels, as opposed to those with neural presbycusis (Schuknecht et al., 1974).

The final type of presbycusis is cochlear conductive or mechanical presbycusis. Calcification at the basal end of the cochlea has been theorised to cause a stiffening of the basilar membrane, which causes the basilar membrane to require additional intensity in order to move and activate the hair cells, thus increasing thresholds (Gacek & Schuknecht, 1969). This hearing loss cannot be explained by either sensory or neural loss found in post-mortem analysis (Connelly, 2003). Post-mortem analysis was performed on temporal bones by Schuknecht (1964). The typical hearing loss

configuration associated with this particular pathology was a sloping high frequency hearing loss. This type of presbycusis is typically progressive (Connelly, 2003).

Many people exhibit a combination of these types of presbycusis, meaning it is hard to place patients into a distinct category (Mazelová, Popelar, & Syka, 2003). Additionally, the peripheral structures are not the only structures which are affected: the central auditory structures also experience age-related deterioration called central auditory processing disorder or central presbycusis (Gates, 2012; Humes et al., 2012). This is related to the finding that even for older people with relatively normal thresholds as demonstrated by the audiogram, deficits in temporal processing has been shown to begin declining from middle age (Grose & Mamo, 2010). Hearing aid use may provide peripheral input to the hearing impaired ear, but the ability of the user to make use of these sounds via central processing may be limited (Tremblay, 2015). The concept of central presbycusis has been highlighted as requiring additional research (Humes et al., 2012).

An important point to consider is the increasing percentage of the population affected by age-related hearing loss. Methods of treatment of hearing loss and the use of aural rehabilitation should be considered to improve communication and therefore quality of life for the aging population (Ciorba et al., 2012).

2.3.4 Effects of Hearing Loss

This section discusses potential effects hearing loss can have on an individual, as examined from two angles – the inability to hear and the social ramifications of hearing loss. An explanation of the physiology and theories associated with inability to hear, specifically why people with hearing loss struggle in noise, will be provided. This is examined in conjunction with auditory selective attention, a cognitive aspect this project focusses on. The second half of the section discusses individual effects associated with an inability to hear – in particular, social and emotional ramifications, which can be severe (Ciorba et al., 2012; Perissinotto, Cenzer, & Covinsky, 2012).

2.3.4.1 Difficulty Hearing

Unsurprisingly people with damage to the cochlea, the organ of auditory perception, experience difficulty hearing (Gates & Mills, 2005). This is due to damage to the hair cells which respond to sound energy entering the cochlea (Ko, 2010). However, it is not only that sound(s) are less audible, but it is also more difficult to separate the sounds i.e., people with hearing loss are less able to discriminate separate noise sources (Bayat et al., 2013). In daily life, this manifests into people with hearing impairment being able to hear less well in noise (Bayat et al., 2013).

This is related to auditory selective attention – the ability to focus on something which the brain needs to focus on, in the presence of perceptual ‘objects’ which are competing for attention. The theory which has been proposed to explain how the brain is able to do this is auditory scene analysis (ASA) (Bregman, 1990). The brain groups similar perceptual inputs into separate ‘auditory streams’, and is able to focus on the target stream while the brain filters out the unwanted noise (Bregman, 1990, p. 3; Cherry, 1953).

ASA ability has been shown to be decreased in people with hearing loss (Bayat et al., 2013). A recent study found that adults with mild-to-moderate sensorineural hearing loss performed significantly worse compared to people with normal hearing in an ASA ability test (Bayat et al., 2013). Additionally, older people with hearing loss have decreased auditory selective attention abilities, due to cognitive decline (Barr & Giambra, 1990; Commodari & Guarnera, 2008; Panek & Rush, 1981). Older research participants have been shown to have less selective attentional control than younger participants, resulting in diminished ability to ignore distractor-stimuli (Fabiani & Gratton, 2013). Middle-aged participants performed significantly poorer than younger adults when trying to recognise speech which was being masked by another speaker, demonstrating the relatively early impact of these deficits in complex listening environments (Helfer & Vargo, 2009). The combination of reduced ASA abilities and reduced attention abilities can make it very difficult for older people with hearing loss to hear in noisy situations (Bayat et al., 2013).

Clinical questionnaires used as self-assessment tools highlight this fact. The Speech, Spatial and Qualities of Hearing Scale (SSQ) identifies the areas where people with hearing loss have the

most difficulty (Gatehouse & Noble, 2004). It consists of three subscales: speech, spatial and quality. Speech focuses on different listening situations, spatial emphasises sound localization ability, and quality centres on perception and listening effort (Singh & Pichora-Fuller, 2010). A 2004 study administered the SSQ to 153 older participants with hearing loss prior to being fit with hearing aids (Gatehouse & Noble, 2004). The results showed that identification of speech and attention were the areas that people struggled with most. The most difficult listening situations concerned those involving more than one auditory stream, and when participants were trying to listen in background noise (Gatehouse & Noble, 2004). As this self-assessment tool may help identify attention deficits in older people with hearing loss, it lends support for associated decreases in selective attention and reduced ASA abilities. The SSQ highlights situations where such decrements will likely have the greatest subjective impact – in noise, and when competing signals are present.

2.3.4.2 *Effects on the Person*

This section details secondary issues arising from the inability to hear as well as the social and emotional effects for the affected individual, brought on by hearing loss.

The ability to easily communicate with companions and friends reduces social isolation (Mick et al., 2014). Social isolation in the elderly decreases quality of life, and is a predictor of functional decline and death (Perissinotto et al., 2012). For people with hearing loss who have a partner, the inability to communicate with spouses has been shown to increase anxiety and stress in couples where one has a hearing loss (Hétu et al., 1988). The spouse without hearing loss may feel restricted socially, even though they themselves have no impairment (Piercy & Piercy, 2002). A recent study found women between 60-69 years old had increased odds of social isolation as the severity of their hearing loss increased (Mick et al., 2014). This was thought to reflect the use of verbal communication by women to increase intimacy and connections with people, while men used language as a vehicle to achieve tasks (Mick et al., 2014).

Social isolation is related to overall quality of life (Fallowfield, 2009). Quality of life is the “physical, functional, social and emotional well-being of an individual” (Fallowfield, 2009, p. 1). It encompasses social interactions, but also considers other aspects. Dalton et al. (2003) found that in

older adults (53-97 years old), as the severity of the hearing loss increased, the quality of life decreased. A more recent study found that when comparing older people with and without hearing loss, only 39% of participants with hearing loss felt they had ‘excellent’ quality of life, compared to 68% of people without hearing loss (Ciorba et al., 2012). The study also found that almost one-third of people with hearing loss reported “fair” or “poor” health, compared to just 9% of people without hearing loss (Ciorba et al., 2012). The impact on the life of the individual with hearing loss and the communication partners in their life can be severe (Perissinotto et al., 2012), and thus supports the use of treatments and strategies for the management of hearing loss (Ciorba et al., 2012).

Hearing loss has also been shown to be linked with greater cognitive decline and associated with cognitive impairment in elderly individuals (Lin et al., 2013). The severity of the hearing loss can affect the severity of the cognitive decline (Lin, 2011). In particular, greater hearing loss has been associated with lower scores on tests of executive function and psychomotor processing (Lin, 2011). The author acknowledged future research was required to ascertain if hearing loss could be a modifiable later-life contributor to cognitive decline or an early index of such cognitive deterioration (Lin, 2011). Another study found similar results, with more severe hearing loss associated with additional decline in measures of memory, executive function and general cognition, after accounting for potential confounders such as age, sex and education (Lin et al., 2011).

2.4 Hearing Aids

Given the effect on quality of life, the need for the treatment and management of hearing loss appears obvious (Ciorba et al., 2012). A common treatment for hearing loss is hearing aids (Golabek et al., 1988). The use and benefits of hearing aids will be discussed.

2.4.1 Hearing Aid Explanation

This section provides a brief explanation of hearing aid operation. Detailed coverage of the topic of hearing aids can be found in Dillon (2012). Typically a hearing aid has three main components: one or two microphones; an amplifier; and a receiver (Dillon, 2012). The sound enters

the microphone, which converts the acoustic sound waves into electricity. This electrical signal is increased in voltage and current by the amplifier, which draws power from the battery, causing the electrical output to be larger than the input from the microphone (Dillon, 2012). Finally, the receiver converts this amplified electrical signal into an acoustic output signal, which is delivered to the ear of the individual with hearing impairment (Dillon, 2012).

Along the way, there are additional modifications which hearing aids are able to make to the signal, in order to make the sound more natural or pleasant for the individual's hearing loss and preference (Dillon, 2012). For example, depending on the type and settings, some directional microphones may allow sound coming from directly in front of the listener to be amplified greater than sounds arriving from the rear, enabling background noise to be reduced in relation to a speaker standing in front of the listener (Dillon, 2012). Compression is used in amplifiers, so that all input intensities are not amplified equally, to prevent a person with hearing impairment from receiving excessively high intensity sound from the aid. Additionally, compression allows soft sounds to be amplified more than loud sounds: to make quiet sounds more audible to the person with hearing impairment (Dillon, 2012). Thus as the gain of the input signal increases the amount of amplification decreases. There are also additional accessories which can be used in conjunction with hearing aids, such as remote controls and Frequency Modulated systems (FM systems, also known as remote microphone systems) (Dillon, 2012), enabling user control and improved access to signals occurring at a distance or embedded in ambient noise (Dillon, 2012). Recent advances in wireless technology means that hearing aids are also able to stream using Bluetooth through mobile phones, TVs, and music devices (Dillon, 2012).

Although hearing aids are clearly able to use sophisticated technology to provide sufficient peripheral input to the cochlea supporting sound and speech audibility, central neural issues caused by hearing loss may reduce speech perception (Pelle, Johnsrude, & Davis, 2010) .

2.4.2 Hearing Aids and Neural Plasticity

For most people with sensorineural hearing loss, there are varying degrees of damage to the outer or inner hair cells. Sometimes the cochlea will fail to elicit neural firing in one region, called a

dead region (Dillon, 2012). The neurons in this section will not respond to sound; instead these neurons will prefer to respond to adjacent frequencies, which are being more effectively processed by the cochlea (Kluk & Moore, 2006). When dead regions containing damaged hair cells are being stimulated by amplified sound, the dead regions will still not respond to frequencies associated with the area of damage (Kluk & Moore, 2006). Neural plasticity theories suggest that the neural pathways of the central auditory system should be able to reorganise themselves following restoration of peripheral input, although some studies have not been able to draw definite conclusions (Palmer, Nelson, & Lindley, 1998).

Animal trials have tried to replicate hearing loss in order to investigate neural plasticity (Kaltenbach, Czaja, & Kaplan, 1992; Willott, 1984). Mice that have been genetically engineered to experience progressive high frequency hearing loss similar to that of sensory presbycusis (Willott, 1984). These animals have been shown to have neurons that have changed from responding to high frequency sounds, to responding to middle and low frequency sounds that are more readily audible; as high frequency loss increases (Willott, 1984). Kaltenbach et al. (1992) showed similar tonotopic reorganisation of the central auditory system following noise-induced hearing loss in adult hamsters (Kaltenbach et al., 1992).

These studies demonstrate that peripheral auditory deprivation can change the central neural pathways of the auditory cortex. It is thought that this reorganisation can explain reduced speech perception abilities for individuals with hearing impairment, as they are no longer able to discriminate speech segments as accurately (Peelle et al., 2010). There is a large body of recent literature around hearing loss and neural plasticity, or the reorganisation of the central auditory system (Huetz, Guedin, & Edeline, 2014; Kral, Heid, Hubka, & Tillein, 2013; Peelle et al., 2010), although it is not possible to draw definite conclusions yet (Wingfield & Peelle, 2015). Thus, it remains unknown as to what extent restoration of peripheral input could have on central auditory systems.

2.4.3 Hearing Aid Use

Hearing aids are a proven, common method used to reduce the daily listening struggles that those with hearing loss experience (Golabek et al., 1988). The most advanced hearing aids can: have

directional microphones, reduce wind noise, be programmed with different options for different situations (e.g., music) and can be controlled through smartphones (Dillon, 2012). However, a recent study found only 11% of Australians between 49 and 99 years old with a hearing loss owned a hearing aid and of the 11% who had a hearing aid, 24% never used it (D. Hartley, Rochtchina, Newall, Golding, & Mitchell, 2010). Another study found that in people over 85 years of age, of which the majority had a significant hearing impairment, only 26.5% used hearing aids (Kiely, Gopinath, Mitchell, Luszcz, & Anstey, 2012). There is an identified need to study the reasons behind low hearing aid uptake and use (Knusden, Öberg, Nielsen, Naylor, & Kramer, 2010). Common problems experienced by people which prevent them from using hearing aids include: physical discomfort, loudness discomfort, whistling or feedback, their own voice sounding subjectively unusual, overall sound quality is unnatural, and an inability to operate the aid (Dillon, 2012).

For older people with hearing loss, there has been some research investigating hearing aid uptake and outcomes (Öberg et al., 2012). A study involving 85-year-old hearing impaired residents of the city of Linköping, Sweden, cited the most frequent reason for not acquiring hearing aids was that they did not think their hearing loss was severe enough to warrant amplification (Öberg et al., 2012). Of those participants who did have hearing aids, 12% reported not using the aids (Öberg et al., 2012). However, 55% of hearing aid wearers reported that their use of a hearing aid increased their quality of life as measured by the International Outcome Inventory for Hearing Aids by “quite a lot better” or “very much better” (Öberg et al., 2012, p. 110). When considering hearing aids for the old-old population, i.e. those over 85 years old, it is important to look at their audiological status as a part of a broader rehabilitation approach, as often these people will have additional cognitive impairment and comorbidities (Pichora-Fuller, Dupuis, Reed, & Lemke, 2013).

Although there are great advances in hearing aid technology, as well as research into solutions for common problems experienced by hearing aid users (Dillon, 2012), there are other barriers preventing people from acquiring hearing aids (Erler & Garstecki, 2002). One of these barriers is stigma. A study looking into the viewpoints of women in different age groups found that there were negative perceptions associated with hearing loss and hearing aids, although less stigma was associated with hearing loss (Erler & Garstecki, 2002). Older women also perceive less stigma than

their younger counterparts (Erler & Garstecki, 2002). In 1977, a study found that adults associated greater negative attributes to children with hearing aids, than those who did not, which came to be known as the ‘hearing aid effect’ (Blood, Blood, & Danhauer, 1977, p. 12). Recently, Rauterkus and Palmer (2014) repeated a similar study, and found this effect was not evident; with young hearing aid users not rating their device use more negatively compared to non-hearing aid counterparts. This suggests a shift in opinions about hearing aids and negative preconceptions such as the ‘hearing aid effect’ may be resolving over time. Kochkin (2012) identified stigma as the most important psychosocial barrier to using hearing aids, and suggested that continued reinforcement of the low visibility of hearing aids was a method to combat this, as well as adjunct counselling provision.

2.4.4 Hearing Aid Benefits

The low uptake of hearing aids are particularly interesting as they are proven to improve quality of life in older people with hearing loss (Mulrow et al., 1990; Öberg et al., 2012; Tsakirpoulou et al., 2007). 80% of participants reported significant benefits from hearing aids use in three measured domains: social, general and physical (Tsakirpoulou et al., 2007). This finding has also been supported by older studies such as Mulrow et al. (1990), which found improvements in hearing impaired veterans in: social, emotional, communicative and cognitive function, as well as lower rates of depression (Mulrow et al., 1990).

A study that used a version of the self-assessment quality of life tool used in this project (the Hearing Handicap Inventory for the Elderly: Screening Version) reported significant improvements in scores following six months post-fitting, after trialling hearing aids for the first time (Vuorialho, Karinen, & Sorri, 2006). This finding was evident for all participants fit with only one hearing aid i.e. monaurally (Vuorialho et al., 2006).

2.4.5 Hearing Aids and Cognition

Although hearing aids and quality-of-life among older participants has been studied extensively, there are limited studies focussing on hearing aids and cognition, and these studies do not draw clear conclusions (Kalluri & Humes, 2012). In a recent study, hearing aid use was associated

with better cognition, although the authors were unsure if this was due to self-efficacy improvements (Dawes et al., 2015). A systematic review noted hearing aids can impact immediate short-term outcomes, although the long-term effects were unknown (Kalluri & Humes, 2012).

A hearing device-related research project found that participants with greater hearing loss performed significantly worse on a cognitive test of executive function (Lin, 2011). The same study also determined that hearing aid use was positively associated with scores of this test, suggesting links between hearing aid use and improved cognition (Lin, 2011). However, another study revealed that hearing aid use was not associated with any cognitive decline, although again, greater hearing loss was associated with significantly poorer scores on memory and executive function (Lin et al., 2011). This was supported by a further study, with participants who demonstrated greater hearing loss, performing significantly worse on tests of cognition than their normal hearing peers (Lin et al., 2013). Both studies called for additional research into hearing rehabilitation or hearing aid use and reducing or arresting cognitive decline in older adults (Lin, 2011; Lin et al., 2013).

Another study, focussing on working memory and hearing aids, was inconclusive regarding the effect of hearing aids on working memory, asserting that differences in experiences were dependent on the individual hearing aid user (Lunner et al., 2009). It has since been suggested that people with preserved or greater working memory capabilities do better with advanced signal processing hearing aids, as the brain is able to hold the input for longer in cognitive stores, in order to process and understand it (Rudner & Lunner, 2013). For people with hearing impairment, difficult listening situations require more working memory interaction, using context and prior knowledge to comprehend the speaker (Lunner et al., 2009). Thus, for individuals with accelerated cognitive aging, effecting working memory due to their hearing loss, their speech comprehension abilities may be further compromised; not only by their hearing loss but also by their additional decline in working memory.

Multiple studies suggested that there exists a need for further research into this area (Dawes et al., 2015; Kalluri & Humes, 2012; Lin et al., 2013).

2.5 Cognition and Hearing Loss

2.5.1 Introduction

This section aims to clearly connect the three previous sections – cognitive aging, cognitive training, and hearing loss – to focus on the relationship between cognition and hearing loss, which is the primary theme of this research. It will begin with a description of studies pertaining to cognition and hearing loss, to look at previous literature highlighting the need to understand the effect hearing loss has on cognition (Lin et al., 2013; Quaranta et al., 2014; Uhlmann, Larson, Rees, Koepsell, & Duckert, 1989; Valentijn et al., 2005). Three theories to explain the phenomena of accelerated cognitive decline and hearing loss will be discussed (Lindenberger & Baltes, 1994; Mick et al., 2014; Sweller, Ayres, & Kalyuga, 2011). Following this, studies involving attempts to improve cognition in the specific population of older participants with hearing loss will be discussed (Acar et al., 2010; Anderson, White-Schwoch, Parberry-Clark, & Kraus, 2013; Choi et al., 2011; Mulrow et al., 1990). The intervention methods used in these studies will also be considered. This project will attempt to draw conclusions from the evidence base presented and provide support for the need for this present study.

2.5.2 Hearing Loss and Accelerated Cognitive Decline

2.5.2.1 *The Evidence Base*

The concept that people with hearing loss may experience accelerated cognitive aging is not a new one. A study from 1989 found that people with dementia had a much higher prevalence of significant hearing loss than their age-, sex- and education-matched peers without dementia (Uhlmann et al., 1989). The same study found participants with more severe hearing loss also had a higher adjusted relative odds of having dementia (Uhlmann et al., 1989). A similar study undertaken more recently and focusing on dementia and hearing loss, found that mild cognitive impairment was significantly associated with hearing loss (Quaranta et al., 2014).

A longitudinal study conducted over 6 years found that changes in hearing predicted changes in measures of memory, selective attention and processing speed (Valentijn et al., 2005). Participants who gained hearing aids during this time showed no significant differences from the predicted outcomes, however the sample size was only 7 participants (Valentijn et al., 2005). A more recent study, with a much larger participant size ($n = 1984$) and conducted over 6 years, found that participants with hearing loss at the beginning of the study showed significantly larger declines in measures of executive and global cognitive function than those with normal hearing (Lin et al., 2013). Additionally, all those identified with hearing loss had an increased risk of incident cognitive impairment; linearly associated with the severity of the hearing loss (Lin et al., 2013). The authors identified the need for research to determine whether hearing technologies could slow these effects (Lin et al., 2013). Another study looked at the effect of hearing loss on both cognition and speech recognition (Helfer & Freyman, 2014). Older participants with greater hearing loss showed poorer speech understanding, and also poorer cognitive scores on all measured domains: working memory, short-term memory, processing speed/executive function, and inhibitory ability (Helfer & Freyman, 2014). A longitudinal Australian study with 2441 participants tested over 11 years found the incidence of probable cognitive impairment was also associated with higher hearing thresholds (Kiely et al., 2012). However, the only cognitive testing these participants underwent was the Mini-Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975), an 11 item questionnaire which usually

takes 5-10 minutes to administer. This likely provided limited cognitive testing; due to the MMSE's status as a screening tool, rather than a sensitive or specific measure of cognitive impairment (Kiely et al., 2012).

2.5.2.2 Possible Explanations

Clearly, multiple studies have linked accelerated cognitive decline with hearing impairment, and even further, the severity of that hearing impairment (Lin et al., 2013; Quaranta et al., 2014; Uhlmann et al., 1989; Valentijn et al., 2005). There are three theories which will be considered to explain this phenomenon. The first is that hearing loss leads to difficulties in communication, which means that the individual is not being as socially active as they were before experiencing hearing loss (Mick et al., 2014). Social isolation has been proven to be a predictor of functional decline (Perissinotto et al., 2012). Greater hearing loss has been shown to be associated with increased social isolation in women aged 60-69 (Mick et al., 2014). The use of hearing aids has been shown to reduce social isolation (Kochkin & Rogin, 2000). If this theory was correct, then the ability of hearing aids to reduce social isolation could be seen as a potential way to slow cognitive decline.

A second theory is the concept of cognitive load. Cognitive load is the idea that humans can only hold a limited amount of information in working memory, and exceeding this limit reduces the ability to complete tasks efficiently and accurately (Kahneman, 1973; Sweller et al., 2011). It is proposed that the brain of a hearing impaired person requires additional effort and activity to attend to sound, and to understand a target speaker (Martini, Castiglione, Bovo, Vallesi, & Gabelli, 2014). Neuroimaging studies have shown that participants with hearing loss display increased activity in the auditory cortex (Kotak et al., 2005). This is suggested to leave less cognitive capacity for other tasks (Tun, McCoy, & Wingfield, 2009). A study involving car driving found participants with hearing loss performed complex driving and additional tasks significantly worse than normal hearing participants, suggesting the additional cognitive demand was detrimental for hearing impaired participants (Thorslund, Peters, Lodeham, & Lyxell, 2013). Additionally, the brain volume of older adults with hearing loss has been shown to decline at an accelerated rate (Lin et al., 2014).

The third theory consists of the idea that there is a common underlying cause, which effects both cognitive function and sensory function (Lindenberger & Baltes, 1994; Lindenberger & Ghisletta, 2009). Central and peripheral structures decline with age, which alters associated synapses and neural anatomy (Martini et al., 2014). A study found that the correlation between cognitive and sensory decline was moderate (Lindenberger & Ghisletta, 2009). Interestingly, there is a suggestion that there may be some genetic factor inciting a predisposition to age-related hearing loss, but further research is required (Eyken, Camp, & Laer, 2006). It is recognized that these three theories may overlap and should not be seen as completely separate concepts (Lin et al., 2011; Martini et al., 2014).

2.5.3 Intervention Methods in Older Participants with Hearing Loss

Older people have shown an ability to improve various aspects of cognitive decline through training programs (Ball et al., 2002; Suzuki et al., 2014). Previous sections have discussed the attention deficits seen in older adults (see Section 2.1.3.2) and the ability of older adults to improve through cognitive training (see Section 2.2.2). This section narrows the examined population to only consider older adults with hearing loss, and look at the limited evidence focusing on hearing loss and cognition within this population. The section will focus on intervention trials aimed at discovering if cognition could be improved in older participants with hearing loss. The studies are divided by the method used – hearing aids or cognitive training.

2.5.3.1 *Hearing Aids*

The earliest study, conducted by Mulrow et al. (1990), contained 194 elderly veterans, and randomly assigned them to either receive a hearing aid or placement on a hearing aid waitlist. Baseline and post-intervention tests measured: social and emotional effects of hearing loss, communication difficulties, ability to function, depression, and cognitive function (Mulrow et al., 1990). Cognitive function was assessed using the Short Portable Mental Status Questionnaire (SPMSQ) which is a 10-item task which assesses cognitive function and scores participants on a scale of 1 to 10 (Pfeiffer, 1975). Significant improvements were found in the hearing aid group on the

measurements of social and emotional effects of hearing loss, depression, communication difficulties, and cognitive function (Mulrow et al., 1990). However the SPMSQ is an instrument devised to establish if an intellectual impairment is present, and to what degree (Pfeiffer, 1975). It was not designed to determine specific, individual cognitive ability or function. However, the results are encouraging regarding amplification outcomes and cognitive preservation.

An older cross-sectional study examined the relationship between: hearing impairment, hearing aids, functional status, and depression and cognition in participants over 65 living in southern Italy (Cacciatore et al., 1999). There was a high prevalence of hearing loss in this population. There was also a significant relationship between those with untreated hearing loss and cognitive decline as measured by the Mini-Mental State Examination (MMSE), and depression as measured by the Geriatric Depression Scale (GDS). Scores on the MMSE decreased as hearing loss severity increased. However, the use of hearing aids reduced depression, as measured by the GDS (Cacciatore et al., 1999). The authors concluded that hearing aids can improve the quality of life for older people with hearing loss, and may improve cognition and reduce depression (Cacciatore et al., 1999).

Allen et al. (2003) found conflicting results, although they were examining a slightly different population. The researchers provided hearing aids to participants with dementia who had a mild hearing loss and monitored these participants over 6 months. Regular measures of cognition and psychiatric symptoms, activities of daily living, and burden on caregivers were conducted (Allen et al., 2003). Although the hearing aids were well-accepted by the participants, cognitive function continued to decline in participants. No change was found for psychiatric symptoms, but there was an improvement in hearing handicap (Allen et al., 2003).

A more recent study which used the same measures as Cacciatore et al. (1999), i.e. the MMSE and the GDS, tested first-time hearing aid users prior to, and 3 months following, hearing aid fitting (Acar et al., 2010). All participants showed significant improvements in cognitive function and a decrease in depression as measured by the MMSE and GDS following 3 months of hearing aid use (Acar et al., 2010). The authors suggested there would be benefit in re-testing participants after a year of hearing aid use, to determine if the effects would be long-term (Acar et al., 2010).

A Korean project compared an experimental group of older people fit with hearing aids, and an equivalent control group, not fit with hearing aids (Choi et al., 2011). All participants had sensorineural hearing loss. Participants were tested prior to, and 6 months after, hearing aid fitting (Choi et al., 2011). Scores of short-term memory were significantly improved in the experimental group as were scores of learning ability, as measured by the Korean visual-verbal learning test (VVLT). The control group displayed no significant change in scores. Measures of efficiency of memory and speech discrimination in noise demonstrated no change from baseline to 6 months post-fitting, for either the experimental or control group (Choi et al., 2011). The authors claimed improvements were associated with speech-related cognitive functions, suggesting that hearing aids not only improve audibility, but also may contribute to speech perception abilities controlled by the central auditory system (Choi et al., 2011).

A study which drew different conclusions was conducted by van Hooren et al. (2005). A similar experiment was undertaken, with older hearing impaired participants being either assigned to a hearing aid experimental group or an untreated control group. Participants were measured on various aspects of cognition function. After one year of hearing aid use, the experimental group did not show significant improvements in any aspect of cognitive function when compared to the control group (van Hooren et al., 2005). Thus the authors suggest that hearing aids only restore sensory input, not central pathway activation, and therefore not cognitive function (van Hooren et al., 2005).

2.5.3.2 Cognitive Training

A study applying a different intervention technique for older adults with hearing loss was conducted by Anderson et al. (2013). The study utilized a method of auditory-based cognitive training focusing on temporal processing. Temporal processing is sensitive to cognitive decline, making it more difficult for older adults with hearing impairments to process rapid changes in speech; especially speech in the presence of background noise (Anderson et al., 2013). They compared results at baseline to post-intervention, and also compared the experimental group to the control group. The experimental group demonstrated improvements in: memory, processing speed and speech-in-noise

perception (Anderson et al., 2013). The authors proposed that auditory-based cognitive training could be a useful tool for restoring temporal processing deficits caused by age (Anderson et al., 2013).

A similar study used phoneme discrimination training to examine if this improved hearing and cognitive abilities of older adults with mild hearing loss (Ferguson, Henshaw, Clark, & Moore, 2014). The training was delivered using a computerized auditory training program, undertaken at the homes of the participants. The study was solely training-based; participants did not use hearing aids. The results showed that some of the more complex cognitive tasks, including divided attention tests, improved following training (Ferguson et al., 2014). The authors suggest that auditory training similar to this may produce listening benefits in complex listening situations in daily life (Ferguson et al., 2014).

A systematic review of auditory training studies reveals intervention has been shown to be successful in the management of some adults with hearing loss (Sweetow & Palmer, 2005). The findings of studies by Anderson et al. (2013) and Ferguson et al. (2014) support this claim. Despite this, time restraints and limited financial gain for private practices has restricted the inclusion of auditory training for adults acquiring hearing aids (Anderson & Kraus, 2013).

Computerised cognitive training programs used with older adults have been shown to have comparable or better results to traditional pen and paper methods, without requiring that participants need exceptional technology skills (Kueider et al., 2012). In a study conducted by Ferguson et al. (2014), only one-third of participants considered themselves competent computer users, although the compliance with the training modality (computer) was high. However, there has been a need for high-quality studies identified, regarding computer-based auditory training for those with hearing loss, as recent studies have not held up well to review (Henshaw & Ferguson, 2013).

2.5.3.3 Conclusions

Although some studies note improvements in older participants with hearing loss following some type of cognitive training (Anderson et al., 2013; Ferguson et al., 2014), it is not known how well these improvements translate to real-world environments. Similarly, hearing aids have been shown to improve cognition (Acar et al., 2010; Choi et al., 2011; Mulrow et al., 1990) and reduce

scores on depression scales (Acar et al., 2010; Cacciatore et al., 1999). Conversely, other studies have shown that hearing aids have no preventative effect on cognitive decline (Allen et al., 2003; van Hooren et al., 2005).

Dawes et al. (2015) suggested that improvements in cognition following hearing aid use may be due to increases in self-efficacy. The authors also suggested that more cognitively-able people were more likely to obtain hearing aids, and thus do generally better on tests of cognition (Dawes et al., 2015). There is a clear need to further examine the relationship between rehabilitative strategies, such as hearing aids, and cognition in older participants with hearing loss (Dawes et al., 2015; Kalluri & Humes, 2012; Lin et al., 2013).

2.6 Rationale

Older people have been shown to experience cognitive decline, leading to decreased selective attention abilities, along with other decreased cognitive skills (Commodari & Guarnera, 2008; Panek & Rush, 1981). Older people who have hearing loss have been shown to experience more pronounced cognitive decline, compared to their normal hearing peers (Lin et al., 2013; Valentijn et al., 2005). Due to the rapidly expanding older population it is beneficial for not only the individual, but also the community, for cognition to be maintained for as long as possible using various strategies (Butler et al., 2004).

Hearing aids are a way to treat hearing loss, by restoring peripheral sensory input (Golabek et al., 1988). It is unknown to what extent hearing aids could reduce or slow the effect of hearing loss on cognition (Dawes et al., 2015; Kalluri & Humes, 2012; Lin et al., 2013). Studies involving hearing aids and cognition have found that hearing aids have been shown to improve cognition in older people with hearing loss (Acar et al., 2010; Choi et al., 2011; Mulrow et al., 1990), but not in every study (Allen et al., 2003; van Hooren et al., 2005). However, improvements in quality of life after people have been using hearing aids have been consistently found (Mulrow et al., 1990; Tsakiropoulou et al., 2007; Vuorialho et al., 2006).

Of the studies reviewed and detailed within the Literature Review, 3 primarily focussed on: the elderly population, the fit of hearing aids as a treatment consideration, and some form of cognitive assessment or test battery (Acar et al., 2010; Choi et al., 2011; Mulrow et al., 1990). Of those, only the Korean Choi et al. (2011) study employed a computerised cognitive assessment approach that incorporated tests indexing memory, cognitive learning and speech discrimination (VVLTL). The Acar et al. (2010) and Mulrow et al. (1990) studies used older, short-form, questionnaire-based exam methods (MMSE and SPMSQ, respectively, (Pfeiffer, 1975; Folstein, et al., 1975)). These cognitive exam methods were designed primarily as screening tools providing quick indications of potential cognitive involvement; rather than sensitive, specific diagnosis of a particular cognitive domain or disease (Pfeiffer, 1975; Folstein, et al., 1975). For measures taken prior to and 6 months after aid

fitting, the Choi et al. (2011) study revealed significant improvements in short-term memory and learning ability for the experimental group comprised of elderly hearing aid patients ($n = 18$), compared to controls ($n = 11$) who did not use hearing aids. Therefore, the Choi et al. (2011) study could be considered an exemplar study.

For the present study English-language, normed, computerised tests incorporating memory and the discrimination of competing speech (Humes et al., 2006) are employed; and a control group is included, all consistent with Choi et al. (2011). The duration of the present study adheres to the time constraints of a Master-level thesis (an academic year) and it is acknowledged the methodology's timing represents a conservative duration, shorter than the 6 months accorded the Choi et al. (2011) study. It is also acknowledged that similar participant numbers although sought, could potentially prove challenging as the Choi et al. (2011) study sourced patients from a large, hospital-based otology clinic. Due to the small evidence base of studies investigating hearing aids and cognition and the lack of any historical evidence for such studies occurring in New Zealand, the current study is considered exploratory in nature.

The aims of the study were:

1. Determine if individuals with hearing loss are at risk for selective attention and working memory cognitive deficits.
2. Determine if hearing aid fitting is sufficient to improve or arrest aspects of hearing loss-related cognitive decline particularly, selective attention and working memory.

Participants were assessed for selective attention abilities by means of a dichotic listening task to discover whether selective auditory attention abilities were reduced compared to normative data for people with hearing loss, and also to determine if auditory selective attention abilities showed improvement following 3 weeks of hearing aid use. A dichotic listening task is one where participants are presented with a target sentence from which they are required to gain some piece of information, while ignoring a similar distractor sentence (Humes et al., 2006). The participants were signalled as to which sentence to listen to (target) by a call signal word (Humes et al., 2006). This is based on a task used and piloted by Humes et al. (2006)

Participants were assessed for working memory abilities by means of an auditory digit span task to discover whether working memory abilities were reduced compared to normative data for people with hearing loss, and also to determine if working memory abilities showed improvement following 3 weeks of hearing aid use. A digit span task involves a participant hearing a sequence of digits, and recalling those digits – either in forward order, backward order or in sequential order (Lumley & Calhoun, 1934). The ‘span’ is the maximum number of digits that can be correctly recalled (Lumley & Calhoun, 1934). The version of digit span used tested participants in two conditions – forward order (forward) and backward order (backward).

The present study also administered two, subjective self-assessment tools before and after a professional hearing aid fitting, to survey perceived hearing handicap and aid benefit: The Hearing Handicap Inventory for Adults (HHIA) and the Abbreviated Profile of Hearing Aid Benefit (APHAB) (R. M. Cox & Alexander, 1995; Newman, Weinstein, Jacobson, & Hug, 1991).

2.7 Hypotheses

The first aim pertained to hearing loss and cognition. Hearing loss is shown to be associated with cognitive decline (Lin et al., 2013; Lin, 2011). Further research is required to better understand these connections (Kalluri & Humes, 2012). This study aimed to see if working memory and auditory selective attention abilities were reduced in older participants with hearing loss compared to their normal hearing peers. We hypothesized that our participants who had hearing loss would perform worse in cognitive tasks indexing selective auditory attention, than older people with normal hearing. If cognitive decline was shown to be linked with hearing loss, it could be an important consideration in encouraging hearing rehabilitation strategies as a method of preventing cognitive decline.

The second aim pertains to hearing aids and cognition. Hearing aids have been shown to improve quality of life (Tsakirpoulou et al., 2007). There have also been studies showing varying results in the role of hearing aids and different aspects of cognition (Acar et al., 2010; Choi et al., 2011; Dawes et al., 2015; Mulrow et al., 1990). However, the general consensus is that hearing aids have a positive effect on cognition, although the long-term effects are unknown (Kalluri & Humes, 2012). From this, we hypothesize that use of hearing aids over approximately 3 weeks will result in significant improvements in auditory selective attention, as assessed by the dichotic listening task, and working memory, as assessed by digit span.

3 Method

3.1 Participants

3.1.1 Participant Details

3.1.1.1 *Experimental Group*

8 participants, 4 women and 4 men, ranging in age from 51 to 84 years, with a mean age of 69 years old and standard deviation (SD) of 12 years and 4 months, volunteered to participate and form the experimental group.

3.1.1.2 *Control Group*

27 participants, 19 women and 8 men, ranging in age from 60 to 80 years, volunteered to participate and form the control groups. The mean age was 71 years and 9 months (SD = 5 years 8 months).

3.1.1.3 *Normal Hearing Group*

10 participants, 9 women and 1 man, ranging in age from 47 to 72 years, volunteered to participate and form the normal hearing group. The mean age was 58 years and 10 months (SD = 7 years 10 months). Participants received assessment and were determined to have hearing thresholds no greater than 20 dB HL between 250 and 8000 Hz, indicating preserved hearing for the speech-dominant frequency range.

3.1.2 Recruitment and Inclusion Criteria

3.1.2.1 *Experimental Group*

The participants were new hearing aid users who were clients of local, Canterbury-region private audiology practices such as Bay Audiology. Posters approved for placement within the clinic advertised the study to potential participants, to survey for possible interest in research participation. Similarly, approved posters were placed in the waiting rooms of the University of Canterbury Speech and Hearing Clinic and private audiology clinics who had also agreed to be involved in this study. The researcher was also given formal approval to access clinic schedules, to survey for potential participants who would be interested in being invited to participate.

They were considered suitable for study participation as their age and hearing loss characteristics were consistent with the research aims and proposed methodology. In order to be considered for potential participation, the clients had to meet the following criteria:

1. Be new users of hearing aids i.e., it was the first time they were using/wearing hearing aids.
2. Had decided to purchase/trial hearing aids.
3. Were over 45 years old.
4. Were able to return for follow up appointments with their clinician, with no time constraints i.e., they were able to go through the hearing aid fitting procedure in the standard way, with no alteration to the timing of the standard fitting practise.
5. Were willing to complete questionnaires surveying perceived hearing handicap and hearing aid benefit, and undergo an assessment of auditory selective attention ability and working memory prior-to, and following, the finalization of a standard clinical hearing aid fitting procedure.

Participants who met the study's criteria and provided informed consent, indicating willingness to volunteer, were selected to participate in this study and thus formed the experimental group.

3.1.2.2 Control Group

The participants were adults with hearing loss, who did not currently use, and have never used, hearing aids.

The majority of the control group participants ($n = 26$) were recruited through another study, *Understanding how listeners comprehend distorted speech* (McAuliffe & Sinex, in progress). This study was managed by Dr Megan McAuliffe and Dr Donal Sinex, as part of the New Zealand Institute of Language, Brain and Behaviour's research platform. Participants involved in this study were required to be between 60-90 years old, with no previous history of hearing aid use. As part of the study, they underwent a hearing test. At the time of that study, they were asked whether they would be happy to be contacted again for future research possibilities. Those who met the inclusion criteria and had agreed to be contacted again, were sent information about this study and from there chose whether they would like to participate in the current project, providing written permission was gained for their previous hearing test data to be used. Access to these participants was granted for surveying for: potential participation, the best method for contacting them, and the use of their previous data if consenting. As they had already completed a hearing test, provided consent and principle investigators McAuliffe and Sinex provided formal consent to access the audiometric data from the *Understanding how listeners comprehend distorted speech* to be used in the current project, reducing the amount of time participants were required to provide (see Appendix D).

The remaining participant ($n = 1$) was recruited through word-of-mouth. They had no current, existing audiological data, therefore the researcher administered a hearing test prior to the working memory and attention assessments. Audiometry was performed in a sound-treated booth using an industry-standard, GSI-61 clinical Audiometer. The test booth was sound-treated as per the AS ISO 8253.1 (2010) standard covering *Audiometric Test Methods Part 1: Pure-tone air and bone conduction audiometry*, ensuring the test environment was appropriate.

3.1.2.3 Normal Hearing Group

The participants were adults with no hearing loss, i.e. had thresholds no worse than 20 dB HL from 250 to 8000 Hz. Some (n = 4) were identified as having normal hearing while taking part in the aforementioned study, *Understanding how listeners comprehend distorted speech* (McAuliffe & Sinex, in progress). Formal access to participants was granted towards surveying those individuals who had endorsed an interest in research for: potential participation, the best method for contacting them, and the use of their previous data if consenting. At the time of that study, they were asked whether they would be happy to be contacted again for future research possibilities. Those who met the inclusion criteria and had agreed to be contacted again were sent information about this study and from there chose whether they would like to participate in the current project, providing written permission for their previous hearing test data to be used.

The remaining participants (n = 6) were recruited through word-of-mouth. They had no current, existing audiological data, therefore the researcher administered a hearing test prior to the working memory and attention assessments to ensure they had normal hearing. Audiometry for this group was also performed in a sound-treated booth per AS ISO 8253.1 (2010) standards, using a GSI-61 clinical Audiometer.

Participant recruitment was stopped once the required number of participants was reached. At this stage, no further participants from *Understanding how listeners comprehend distorted speech* (McAuliffe & Sinex, in progress) were contacted.

3.1.3 Exclusions

The following criteria excluded individuals from the control or normal hearing groups from participating:

- A significant conductive hearing loss in either ear i.e. 20 dB HL \geq at 3 frequencies.
- Tinnitus which was subjectively described by the participant as being above a 5 on a scale of 1 to 10 of annoyance.

- On-going idiopathic balance issues.
- Hyperacusis.
- Sensorineural hearing loss greater than a severe degree at any frequency across the speech-dominant frequency range (500 – 4000 Hz).
- Significant hearing asymmetry when comparing hearing acuity between the ears, i.e. difference between the ears of ≥ 20 dB HL for 3 or more frequencies across the speech-dominant frequency range (500 – 4000 Hz).

3.2 Measures

3.2.1 Independent Variable: Hearing Aid Use

Participants within the experimental group were fit with hearing aids. Seven participants were fit binaurally, the remaining participant was fit monaurally (left ear fit only). None chose to change or return their hearing aids at the end of the trial period. More information about the hearing aid selected is presented in Table 6 of the Results section.

3.2.2 Dependent Variables

There were four dependent variables: the Abbreviated Profile of Hearing Aid Benefit (APHAB), the Hearing Handicap Inventory for Adults (HHIA), the working memory assessment, and the dichotic listening task to assess auditory selective attention. The HHIA and APHAB were presented aurally, as face-to-face administration has been shown to produce high validity and good test-retest reliability (Newman et al. 1991). Responses were recorded using a password protected laptop. No identifying information was recorded, as each participant had been assigned a participant number.

Both of the listening tasks used to test auditory selective attention and the digit span task were presented using a Hewlett-Packard Envy 15 Notebook PC running Windows 8.1 with an Intel® Core i7-4700MQ processor. The headphones used were Sennheiser HD280 Pro circumaural headphones (frequency response 8-25000 Hz; nominal impedance 64 Ω). The volume of the laptop was initially set at exactly half (50%) and participants would then adjust the intensity of the task-based stimuli to a subjective level which was sufficiently “audible yet comfortable” before proceeding with the task.

3.2.2.1 HHIA

The Hearing Handicap Inventory for Adults (HHIA) is a self-assessment tool with 25 questions intended to measure the social and emotional effects of hearing loss on the participant (Newman et al., 1991). The HHIA was initially designed as the HHI for the Elderly (HHIE)

(Weinstein & Ventry, 1983). The original HHIE (Hearing Handicap Inventory for the Elderly) was developed by Weinstein and Ventry (1983) as a 25-item self-assessment tool to measure perceived social and emotional results of hearing loss. There are two subscales: social, which measures the disability experienced due to the hearing impairment in social situations; and emotional, which relates to how the participant feels about the situations where their hearing loss may cause difficulties. Peer-reviewed research has shown it to be a valid and reliable tool for clinicians (Deepthi & Kasthuri, 2012; Tomioka et al., 2012).

The HHIA was designed to target adults (Newman et al., 1991). It consists of 25 items, still focussing on emotional and social issues caused by hearing impairment, but with more emphasis on situations involving co-workers and clients. It has high test-retest reliability (Newman et al., 1991). Various versions of the HHIE and HHIA are commonly used in New Zealand clinics and internationally, to compare the handicap experienced before being fitted with hearing aids and after being fitted with hearing aids (Chisolm et al., 2007).

Participants were read the question by the researcher, and be able to choose ‘Yes’, ‘Sometimes’, or ‘No’ as their answer. An answer of ‘Yes’ scores 4 points, ‘Sometimes’ scores 2 points, and ‘No’ scores 0 points. A higher score indicates a greater level of handicap caused by the hearing difficulty. Through face-to-face administration, a change in score of at least 12 points is required to be significant (Newman et al., 1991). A copy of the HHIA is included in Appendix A.

3.2.2.2 APHAB

The Abbreviated Profile of Hearing Aid Benefit (APHAB) is the modified version of a 66-item self-assessment tool, called the Profile of Hearing Aid Performance (R. M. Cox & Gilmore, 1990). From there it developed into the APHAB used today (R. M. Cox & Alexander, 1995). The APHAB uses a subset of 24 of the original 66 items, divisible into four 6-item subscales. These four subscales measure ease of communication, listening in background noise, reverberation and aversiveness of sounds. The first three subscales focus on typical listening situations and experiences, while aversiveness of sounds focuses on whether environmental sounds are uncomfortable to the new hearing aid user.

The APHAB is designed to be administered under two conditions: prior-to being fit with the hearing aid (called the “Unaided” condition) and after being fit with and using the aid for some time (called the “Aided” condition). The difference between the two scores is the level of benefit which the hearing aids have provided in the different situations surveyed. Its use enables the clinician to identify areas where the user might still be having trouble, and similarly gives the client the opportunity to reflect on the level of help which the hearing aids have provided. Test-retest reliability of the APHAB is moderate to high (R. M. Cox & Alexander, 1995) A copy of the APHAB is included in Appendix B.

3.2.2.3 Selective Auditory Attention - Dichotic Listening Task

Both tests of cognitive abilities were presented using Inquisit 4 Web by Millisecond Software (2015). Millisecond Software is a company which offers a library of normed psychological tests for researchers and academics. This project utilised two of their experiments, the auditory selective attention (ASA) task based on Humes et al. (2006) and the digit span (DS) task in the auditory condition based on Lumley and Calhoon (1934).

The auditory selective attention task (ASA) is a dichotic listening assessment which requires participants to attend to a target speaker while the unattended ear is presented with a competing speaker. The two speakers were not the same gender, and the attended speaker was randomly chosen for every trial so that each speaker was the attended speaker half the time. The attended ear was randomly chosen to be either the left ear or the right ear, so that each ear was the attended ear half the time.

The sentence was always presented in the following format: “Ready (call sign), go to (colour) (number) now”. The aim was to listen for the number and the colour spoken by the nominated, attended to speaker, and subsequently respond with the correct colour and number targets. Prior to the two different sentences being presented simultaneously, the particular call sign would briefly appear on the screen, to indicate which speaker to listen to. Thus if “arrow” appeared on the screen, and the male speaker said “Ready baron” while the female speaker said “Ready arrow”, the participant would know to listen to the female speaker to determine what colour and number to choose in response.

Instructions explaining this are seen in Figure 1, and an example of the call sign is presented in Figure 2.

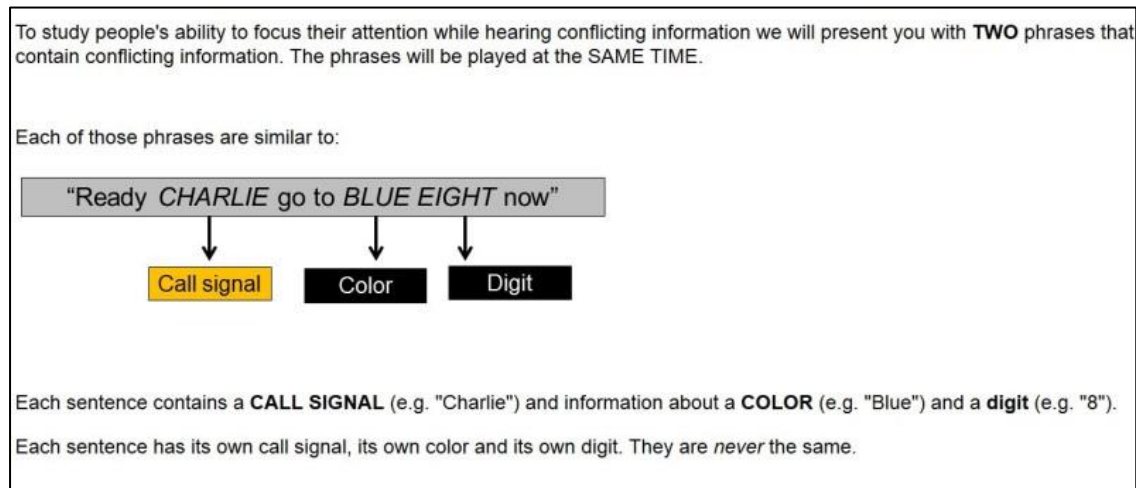


Figure 1. Participant instructions for the computerised auditory selective attention task.

There were eight possible call signs (arrow, baron, Charlie, eagle, hopper, laker, ringo, tiger), four possible colours (white, red, green, blue) and numbers ranged from 1 to 8.



Figure 2. Participant instructions for selectively attending to the nominated call sign.

Once the participant had listened to the sentence, they would select the appropriate colour and number using a mouse. This was explained to the participant, as shown on the screen in Figure 3. After each item, the screen would show a "Continue" option which the participant would select to begin the next item.

Once you have heard both sentences, you will be asked to select the COLOR and the DIGIT of the TARGET sentence from several options on the computer screen:

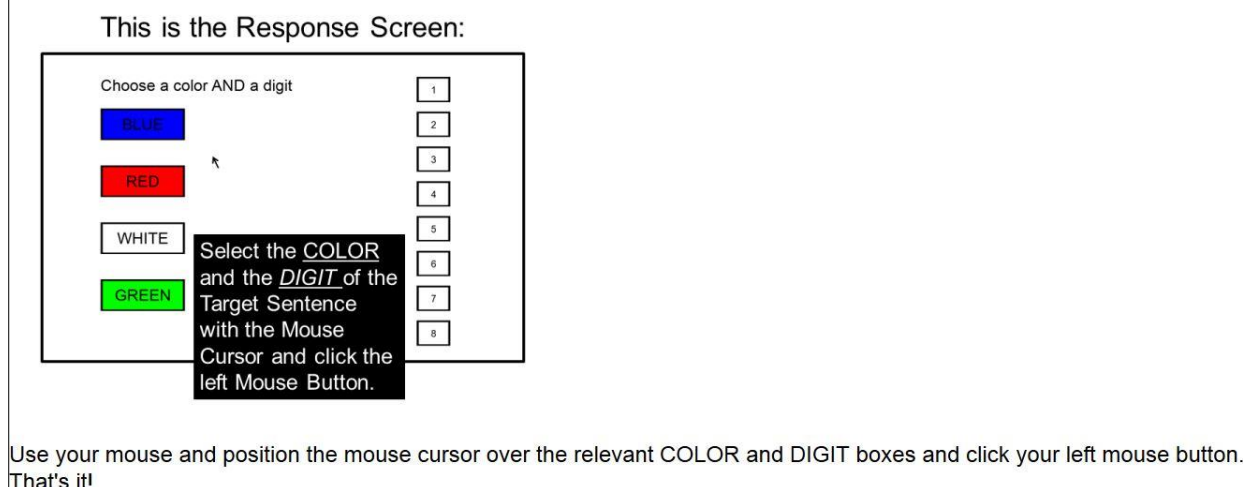


Figure 3. Participant instructions for submitting a response.

The task was divided into 3 blocks of 32 items, one practice block and 2 scored blocks. The rationale for presenting 32 items was due to there being 32 possible number-colour combinations (4 colours multiplied by 8 numbers), so each item was presented once per block. Each call sign was presented 4 times per block. The order of presentation was randomised.

The practice block provided visual feedback to the participant, in the form of "Incorrect!" appearing on the screen after the participant chose the wrong answer. If the participant chose the correct option, no feedback would appear. During the two scored blocks no feedback would appear. An instruction screen explaining to the participants that no feedback would be given appeared upon completion of the practice block.

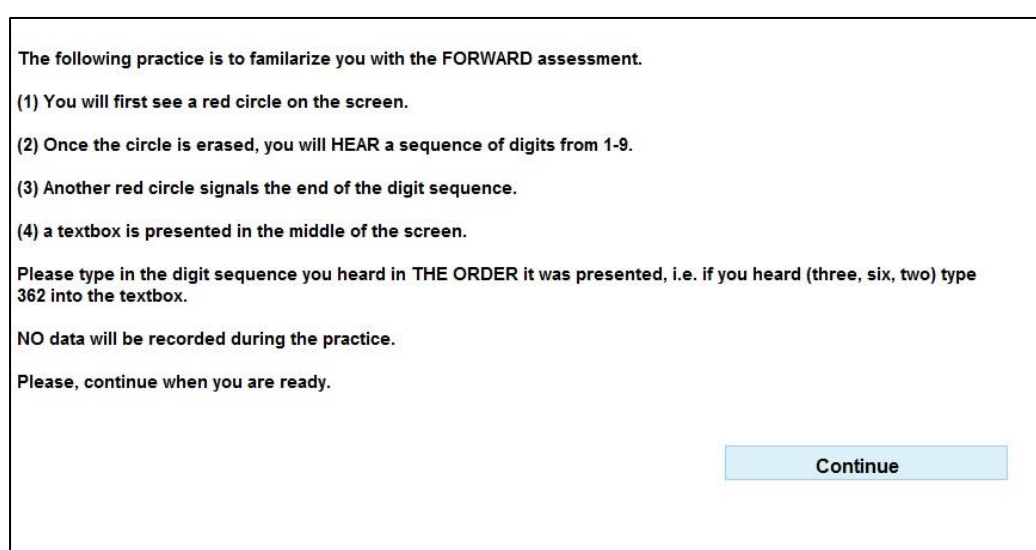
Data collected included whether the participant selected the correct number, correct colour, the combined item score (max = 2), reaction time for the number, reaction time for the colour, the total reaction time, mean reaction time for the number, mean total reaction time, overall percentage correct and the total time taken to complete the task.

3.2.2.4 Working Memory – Digit Span Task

To assess working memory, a digit span task (DS) was administered. Participants were tested under two conditions – forward and backward. In both conditions, participants listened to a female

vocalising a sequence of digits at the rate of one digit per second, and required to type the presented digits into a box on the screen.

Forward condition: In the forward condition, the participant was presented with a group of digits and required to type back exactly what they heard i.e. if the female speaker said “4, 6” the participant had to type “4, 6”. The instructions were presented on the screen as depicted in Figure 4. The participant completed one practice item, and was presented with feedback: either “Your answer is correct” or “Your answer is incorrect”. The participant was then instructed that the actual assessment would begin, and told not to place their fingers on the keyboard before the textbox appeared.



The following practice is to familiarize you with the FORWARD assessment.

- (1) You will first see a red circle on the screen.
- (2) Once the circle is erased, you will HEAR a sequence of digits from 1-9.
- (3) Another red circle signals the end of the digit sequence.
- (4) a textbox is presented in the middle of the screen.

Please type in the digit sequence you heard in THE ORDER it was presented, i.e. if you heard (three, six, two) type 362 into the textbox.

NO data will be recorded during the practice.

Please, continue when you are ready.

Continue

Figure 4. Participant instructions for the digit span (forward) task.

Backward condition: In the backward condition, the participant had to type the presented digits in reverse order i.e. if the female speaker said “7, 5” the participant had to type “5, 7”. The instructions were the same as those in Figure 4, except the example instructed the participant to “type in the digit sequence you heard in the *reverse* order it was presented”. For example, if “three, six, two” was presented and correctly heard, the appropriate response would be to type 263 into the textbox. The participant similarly completed one practice item with appropriate feedback provided.

At the end of each condition, the screen displayed the results for the participant for that condition. The screen showed “the maximum number of digits recalled correctly” and “the maximum number of digits recalled correctly before making two consecutive errors”. It advised the participants that “the second measure is comparable to the traditional assessment of FORWARD/BACKWARD

digit span”. Additionally after this screen for the backward condition, another screen displayed both results, and thanked the participant.

The task started at an easy level, and became progressively more difficult, by increasing the amount of digits being administered. The first level of the forward condition consisted of three presented digits, while the first level of the backward assessment consisted of two presented digits. If the participant correctly typed the answer, the participant increased a level i.e., the presented sequence increased by one digit. If the participant incorrectly typed the answer, the same level was presented a second time. If the participant made another error, the participant moved down a level, starting over for that level. The level prior to the level where the participant made two consecutive errors was recorded as the two-error maximum. This was consistent with the traditional digit span task.

Following finding the two-error maximum, the digit span task continued for 14 trials. This means that the program also recorded the maximum length – the maximum length of digits correctly recalled in the 14 trials. This meant a participant with a two-error maximum of 5 may have had a maximum length of 6, if they got one 6-sequence item correct during one of the 14 trials.

Apart from two-error maximum and maximum length for both conditions, data collected also accounted for the latency of participant responses and the total time taken. Also included in the summary data were the forward mean digit span and the backward mean digit span, or the digit span that a participant was expected to get correct 50% of the time based on overall performance during each condition.

3.2.2.5 *Hearing of Participants*

The four frequency pure-tone average for each participant’s better ear was obtained through the participants’ audiograms. All participants were identified to have hearing loss which was attributed to noise or presbycusis i.e., the participants reported that that their hearing loss was not able to be attributed to a congenital condition, disease or ototoxic medication.

3.3 Procedure

3.3.1 Experimental Group

Every participant ($n = 8$) in the experimental group underwent two sessions of assessment, each taking approximately 40 minutes. The first session occurred on or near the day the client was fitted with their new hearing aids, and the second session occurred when the client was near the end of their hearing aid trial, at least 3 weeks after being fitted with hearing aids. There was one exception, for a participant who was originally part of the control group, but went on to obtain hearing aids. This participant was administered their first session as part of the control group, and then obtained hearing aids two months later. They completed their second session a month after obtaining hearing aids. Audiograms providing behavioural information about individual hearing loss were obtained from clinicians with client's approval at this session.

Each session consisted of four tasks: the HHIA (Newman et al., 1991), the APHAB (R. M. Cox & Alexander, 1995), the digit span working memory task, and auditory selective attention (ASA) task. These tasks were administered via computer notebook to the client in a quiet, private environment, typically spare clinic rooms or empty waiting rooms, with the tasks involving auditory stimuli presented via the Sennheiser 280HD Pro circumaural headphones. The HHIA usually took 5 minutes, the APHAB 10 minutes, the digit span 10 minutes, and the ASA task 15 minutes.

At the end of each client's hearing aid trial process (at least 3-weeks post fitting), each client was re-administered the HHIA, APHAB, digit span and ASA tasks. The results from each client before they obtained hearing aids were compared to their results at the end of the fitting process.

3.3.2 Control Group

Every participant in the control group ($n = 27$) was originally invited to complete one initial session of assessment, taking approximately 30 minutes. Audiograms providing behavioural information about individual hearing loss were obtained either from clinicians or from the previous study, with the participant's approval. The participant who did not have an audiogram (who was

recruited through word-of-mouth), underwent a hearing check administered by the researcher. This was completed prior to the working memory and dichotic listening tasks.

The session consisted of two tasks – the digit span working memory task, and the dichotic listening task, measuring working memory and selective auditory attention ability respectively. These tasks were administered to the participant via computer notebook, while at the University of Canterbury Communication Disorders Department. Participants received a petrol voucher as compensation for the petrol cost associated with this visit. The digit span usually took 10 minutes, and the dichotic listening task 15 minutes.

Following this initial testing, control group participants were invited back, to look for any potential learning effect; i.e. improvements in performance based on exposure to the assessment more than once. The size of any improvements in the control group participants who were tested twice could then be assessed for any possible learning effect. This allowed analysis of the experimental group improvements, with potential learning effects considered. Some control group participants were not available for the second round of testing. Therefore, control group participants who were only tested once ($n = 11$) were called Control Group (S1), referring to the fact they only attended Session 1 (S1). The control group participants who were tested twice ($n = 16$) were called Control Group (S1-S2), referring to the fact they attended both Session 1 (S1) and Session 2 (S2).

Any differences between the experimental group and the control groups were analysed. Figure 5 shows this procedure in a flow chart.

3.3.3 Normal Hearing Group

Every participant ($n = 10$) in the normal hearing group underwent two sessions of assessment, each taking approximately 30 minutes. Audiograms providing behavioural information about individual hearing levels were obtained from the previous study, with the participant's approval. Those participants who did not have an audiogram (those who were recruited through word-of-mouth), underwent a hearing check administered by the researcher. This was completed prior to the working memory and dichotic listening task.

Each session consisted of two tasks – the digit span task, and the dichotic listening task, measuring working memory and selective auditory attention ability respectively. These tasks were administered via computer notebook to the participant, while at the University of Canterbury Communication Disorders Department. The time between these two sessions was a minimal amount of time, to look for a maximum learning effect, i.e. less than 20 days, ideally 10-12 days. Participants received a petrol voucher as compensation for the petrol cost associated with these visits. The digit span usually took 10 minutes, and the dichotic listening task 15 minutes.

Any differences between the groups were analysed. Figure 5 shows this procedure in a flow chart.

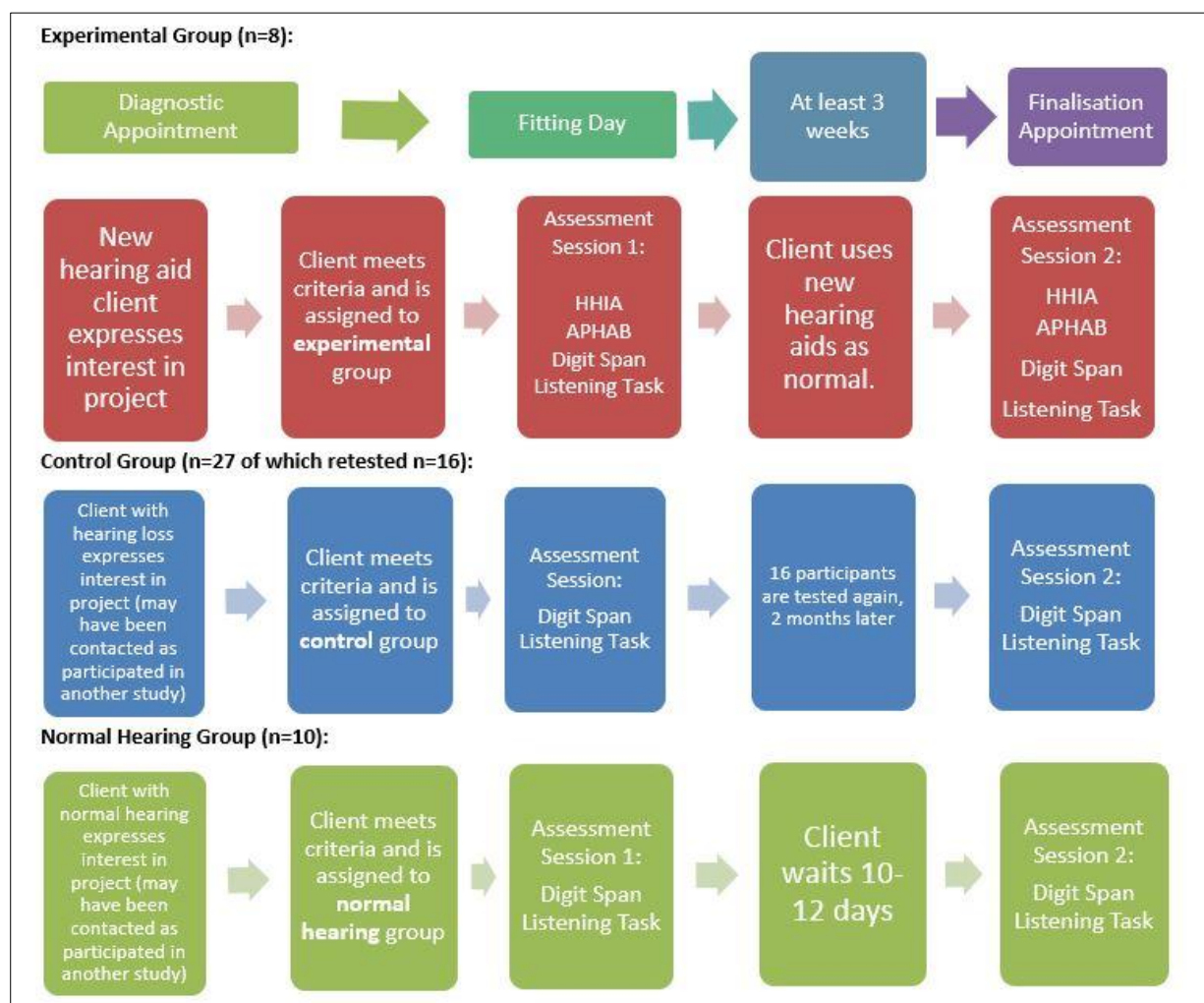


Figure 5. Summary of methodology and participant management.

3.3.4 Study Design

The study was conducted using a mixed study design, consisting of within-group, repeated factors:

1. The auditory selective attention (ASA) test battery.
2. The working memory test battery.

Additionally, there were between-group factors:

1. The experimental group.
2. The control group.
3. The normal hearing group.

3.3.5 Data Collection for Cognitive Testing

The experimental group were tested twice, once on the day they were fit with hearing aids and 3-4 weeks later. This occurred for all participants except one, who was originally part of the control group, and only later decided to get hearing aids, as described in Section 3.3.1 (days between = 112). Excluding this outlier, for the other participants ($n = 7$) the number of days between the two sessions ranged from 20 to 39 days (mean = 26 days, $SD = \pm 6.23$).

The original control group ($n = 27$) were tested once, and then invited back to be tested again, to determine if a second administration of the auditory selective attention and the working memory assessment, would result in any potential procedural learning effect. 16 participants returned for a second session, 11 did not. Those who did not return were referred to as Control Group (S1) ($n = 11$) and those who did return were referred to as Control Group (S1-S2) ($n = 16$). This is demonstrated in Table 1. The decision to retest participants was ultimately made to account for any potential learning effect and followed the majority of data collection, so there were a larger number of days occurring between sessions. The mean number of days between sessions for the control group participants who undertook two sessions (S1-S2) was 72.31 ($SD = \pm 10.21$) with a range from 57 to 87 days.

The normal hearing participants were tested twice to determine if a second administration of the auditory selective attention and the working memory assessments, administered within a

conservative timeframe, would result in any potential procedural learning effect. As per Section 3.3.3, this was to test advantaged participants (no hearing loss) with very short time between sessions, less than 20 days and ideally between 10-12 days. This method and participant group were anticipated to represent the best-case scenario, perform the best with the assessments and potentially produce the most substantial learning effect, if a procedural learning effect was indeed evident. The mean number of days between sessions for the normal hearing participants was 12.2 (SD = ± 2.75) with a range from 8 to 18 days.

Table 1. This demonstrates the difference in number (n) of participants included when comparing the first session with the second session of testing. The shaded box indicates the difference in the control group (CG) between sessions, with 16 participants returning for a second session, while 11 chose not to return. The table also shows the division between the participants who had hearing impairment (HI), and thus consisted of those participants from the experimental group (EG), and control groups (CG), and the normal hearing participants (NH).

	Cognitive Testing	Hearing Loss
Session 1	EG, n = 8	HI, n = 27+8 = 35
	CG, n = 27 (S1)	
	NH, n = 10	NH, n = 10
Session 2	EG, n = 8	HI, n = 16+8 = 24
	CG, n = 16 (S1-S2)	
	NH, n = 10	NH, n = 10

3.4 Statistical Analyses

Three different statistical analyses were undertaken.

The way the data was analysed was guided by the research questions. To determine if hearing aid fitting was sufficient to improve or arrest aspects of hearing loss-related cognitive decline particularly, selective attention and working memory, scores were compared from the experimental group participants before and after hearing aid fitting. Any improvements in either the normal hearing group ($n = 10$) or the control group (S1-S2) participants ($n = 16$) were also examined. This analysis was performed to see if any improvements in cognitive abilities were due to: hearing aid fitting, a procedural learning effect, or a combination of both.

To determine if individuals with hearing loss were at risk for selective attention and working memory cognitive deficits, scores from the first session for all participants with hearing impairment were compared with the normal hearing group. This involved comparing results for all participants from the experimental group ($n = 8$), both control groups (i.e. (S1) ($n = 11$) plus (S1-S2) ($n = 16$) totalling ($n = 35$)), with results obtained from the normal hearing group ($n = 10$). To consider the potential impact of the severity of measured hearing loss, hearing thresholds were analysed in conjunction with cognitive scores.

Finally, each participant's four frequency pure-tone averages were compared to their scores for the digit span task and the dichotic listening task. This was performed to consider the relationship between the severity of the hearing loss and scores on assessments of cognition. This was related to the research aim seeking to determine whether people with hearing loss were more likely to be at risk of memory and attention difficulties, specifically if more severe hearing loss was likely to present with greater cognitive deficits.

Initial a priori consideration suggested at least 20 participants for experimental and control groups, informed by power at .80, alpha at .05 and an effect size of 1. However, the participant numbers did not reach this. Thus, due to the small sample sizes, non-parametric methods were considered for analyses, as data were not normally distributed. Due to the small sample size for the experimental group, the evidence of data outliers, and the experimental design, it was anticipated that

analyses may need to explore in some limited cases, the generation of participant groups matched for size and participant characteristics, to improve power and enable potentially better visualisation of any data trends. Therefore, if data was viewed following any manipulation of sample dynamics (e.g., matching of groups, consideration of sample via outlier removal) it was duly noted. Although considered by some researchers to be solely useful in experimental design (Lenth, 2007), post-hoc power analyses are considered by others to be useful, as they can help when evaluating the merit of non-significant findings, may be useful in considering the value of published findings, and may also be helpful in designing future experiments (Fagley, 1985). Considering this, retrospective power analyses have been presented, specifically when considering matched-group data.

3.5 Ethical Considerations

This project was reviewed and accepted by the University of Canterbury Human Ethics Committee in June 2015 (Reference Code: 2015/34/LR). All procedures carried out during the duration of this study remained in accordance with this. This includes recruitment, consent, privacy, and storage and future use of data.

4 Results

Statistical analyses was carried out using IBM SPSS Statistics 20 for Windows® (SPSS Inc. an IMB Company, 2010).

4.1 Participant Demographics

4.1.1 Age

The age of all participants ($n = 45$) involved in this study ranged from 47 to 84 years old, with a mean age of 68 years and 5 months (\pm standard deviation 9 years and 4 months). There were three groups in this study: the experimental group who were new users of hearing aids; the control group who had hearing impairment but no history of hearing aid use; and a normal hearing group for comparative data.

In the experimental group ($n = 8$) participants ranged from 51 to 84 years old, with a mean age of 69 years old (\pm standard deviation 12 years and 4 months).

In the control group ($n = 27$) participants ranged from 60 to 80 years old, with a mean age of 71 years and 9 months old (\pm standard deviation 5 years and 8 months).

In the normal hearing group ($n = 10$) participants ranged from 47 to 72 years old, with a mean age of 58 years and 10 months old (\pm standard deviation 7 years and 10 months).

This information is shown in Table 2.

Table 2. Age demographics of the experimental group, control group, and normal hearing group. Values are given in years; months.

	Experimental Group	Control Group	Normal Hearing Group
Number of Participants	8	27	10
Mean Age	69	71;9	58;10
Standard Deviation	12;4	5;8	7;10
Age Range	51-84	60-80	47-72
Median Age	74;6	74	58

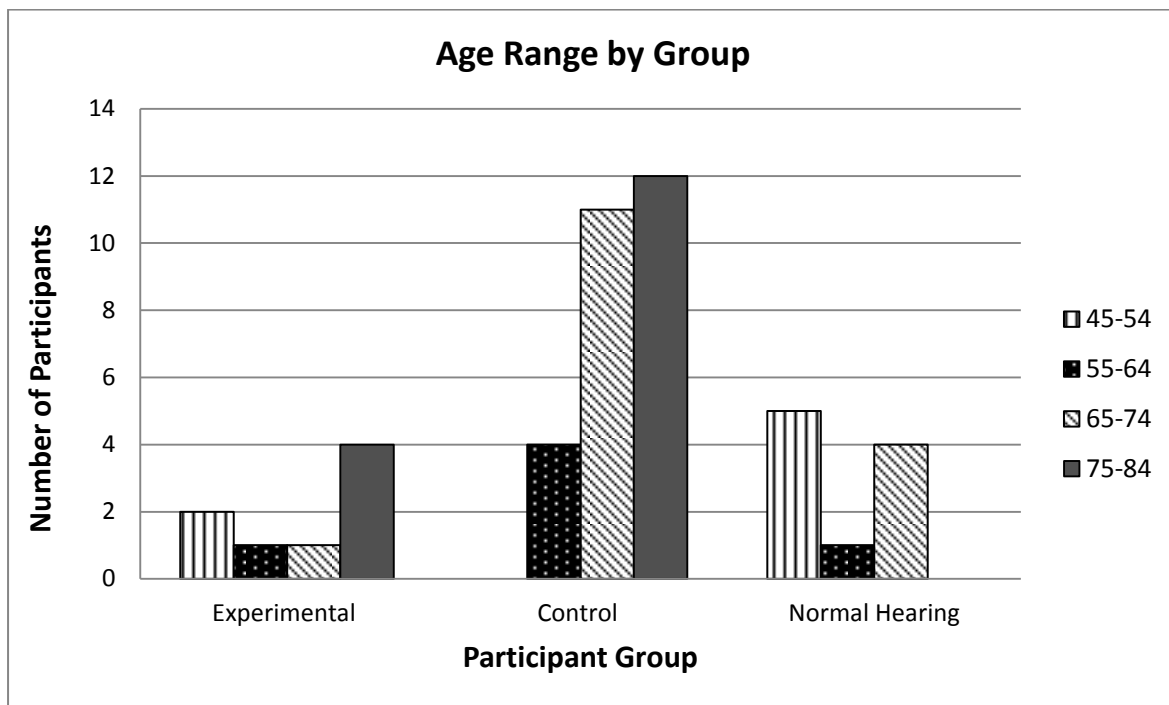


Figure 6. Number of participants in each age range organised by group.

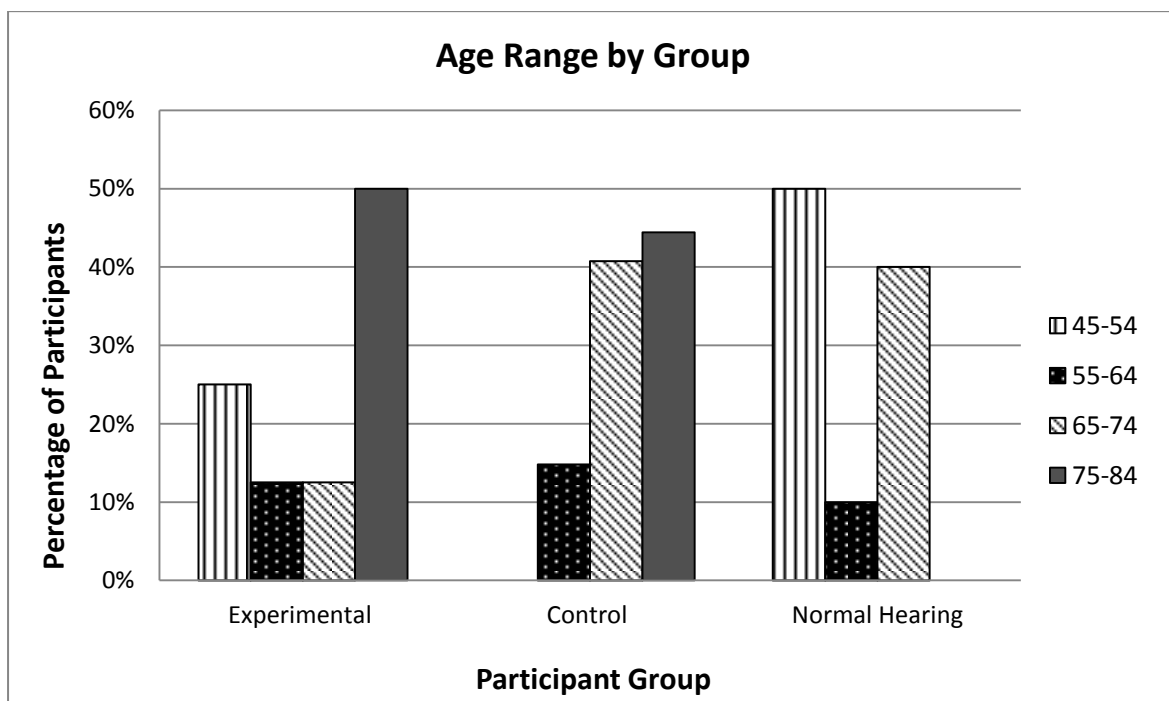


Figure 7. Percentage of participants in each age range organised by group.

4.1.2 Gender

In this study, the majority of the participants were female ($n = 32$ or 71%). In the experimental group ($n = 8$) there were 4 males and 4 females. In the control group ($n = 27$) there were 19 females and 8 males. In the normal hearing group ($n = 10$) there was 1 male and 9 females.

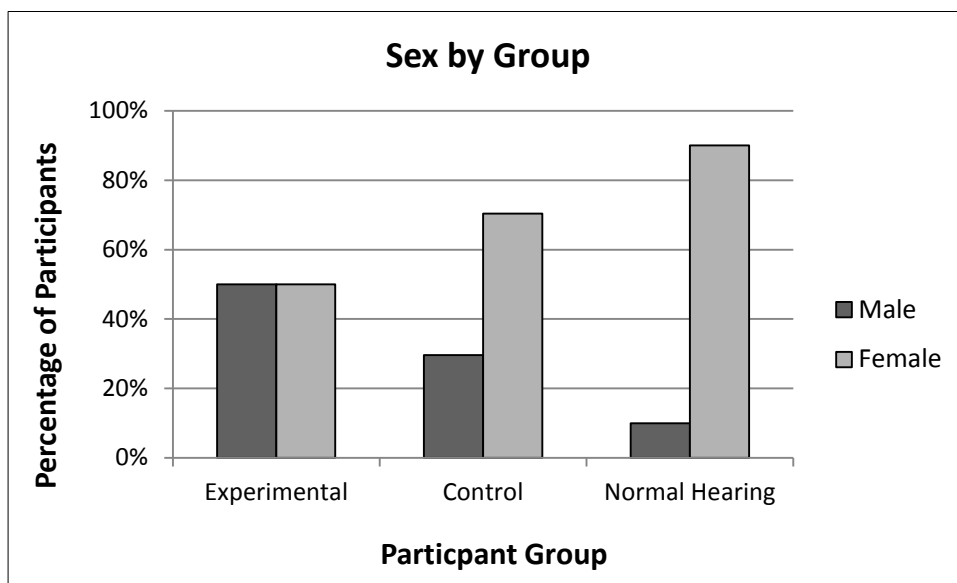


Figure 8. The percentage of male and female participants in each group.

4.1.3 Control Group Comparison

As described in Section 3.3.2, the control group participants were invited back for a second session to look for a potential learning effect, leading to the formation of control group (S1) (n = 27) who attended S1 and control group (S1-S2) (n = 16) who attended both sessions. To better analyse the differences between control group (S1) and control group (S1-S2), the demographic data regarding age and gender is presented below. The data relating to age is very similar between the two groups; however the data relating to gender shows that while control group (S1) has over twice as many females than males, control group (S1-S2) has a much more even distribution.

*Table 3. Age and sex demographics comparing the two control groups.
Values are given in years; months.*

	Control Group (S1)	Control Group (S1-S2)
Number of Participants	27	16
Males: Females	8:19	7:9
Mean Age	71;9	71;6
Standard Deviation	5;8	5;8
Age Range	60-80	60-80
Median Age	74	73;6

4.1.4 Hearing Loss

All participants in the experimental and control groups had some hearing loss. All participants in the normal hearing group had thresholds between 250 and 8000 Hz which were 20dB HL or less.

4.1.4.1 The Experimental Group

The hearing losses of the experimental group were obtained from audiograms performed at diagnostic audiological appointments, prior to their decision to trial hearing aids. This was performed by their clinical audiologist. Most of the participants experienced better hearing in the low frequencies, which deteriorated as frequency increased, creating a sloping high frequency hearing loss. This is the typical hearing loss configuration associated with presbycusis, or age-related hearing loss, as described in Section 2.3.3.2, and Gates and Mills (2005). One participant experienced congenital deafness in her right ear, and obtained no response at maximum presentation levels. This participant had a mild sloping to severe high frequency sensorineural hearing loss in her left ear. This participant was only fit with a hearing aid in the left ear, due to the lack of benefit expected from fitting an aid to the right ear. Every other participant was fit binaurally. One participant (participant number 103) experienced a mixed loss; all other hearing losses were sensorineural. The hearing thresholds for all experimental group participants are shown in Figure 9.

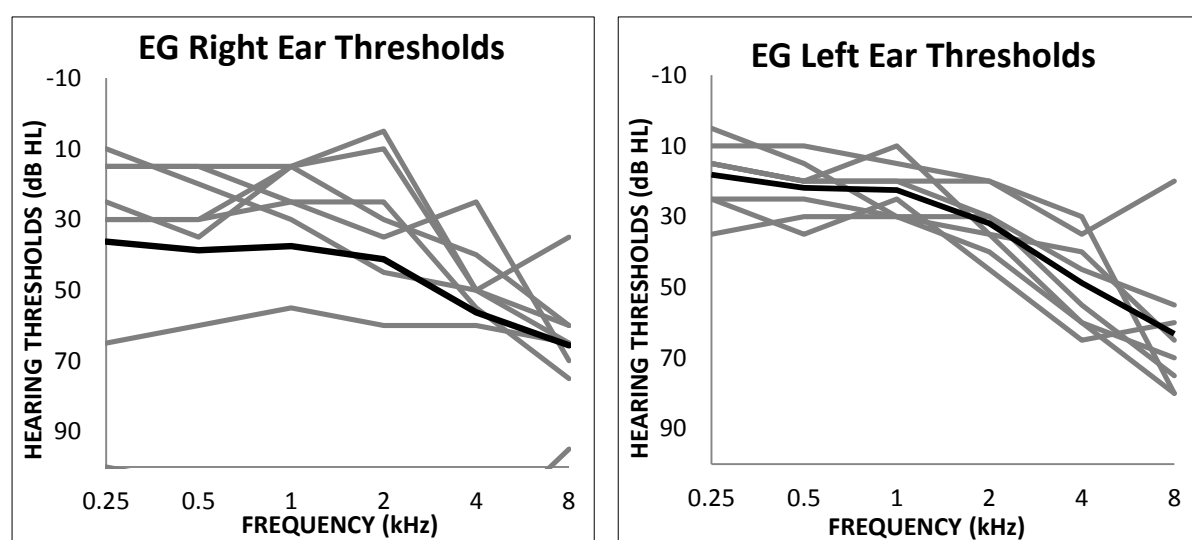


Figure 9. Hearing thresholds for the right and left ears of experimental group (EG) participants ($n = 8$). The dark line indicates the mean thresholds for that ear, while the light lines indicate individual participant thresholds.

4.1.4.2 The Control Group

The hearing losses of the control group were obtained from audiograms obtained through either a research project that they had previously been involved in (McAuliffe & Sinex, in progress), or administered on the day that they completed the attention and memory tasks for the first time. As with the experimental group, most of the participants presented with a sloping high frequency hearing loss.

When comparing the hearing losses of control group (S1) and control group (S2), generally the mean thresholds for the control group (S1) were better (i.e. lower, requiring less intensity for reliable and repeatable ascending responses) than control group (S1-S2). This is true for all frequencies in the right ear and all but 2000 Hz in the left ear. The hearing thresholds for control group (S1) are shown in Figure 10, while the hearing thresholds for control group (S1-S2) are shown in Figure 11. The mean thresholds for the both control groups were better than the experimental group for all frequencies in both ears.

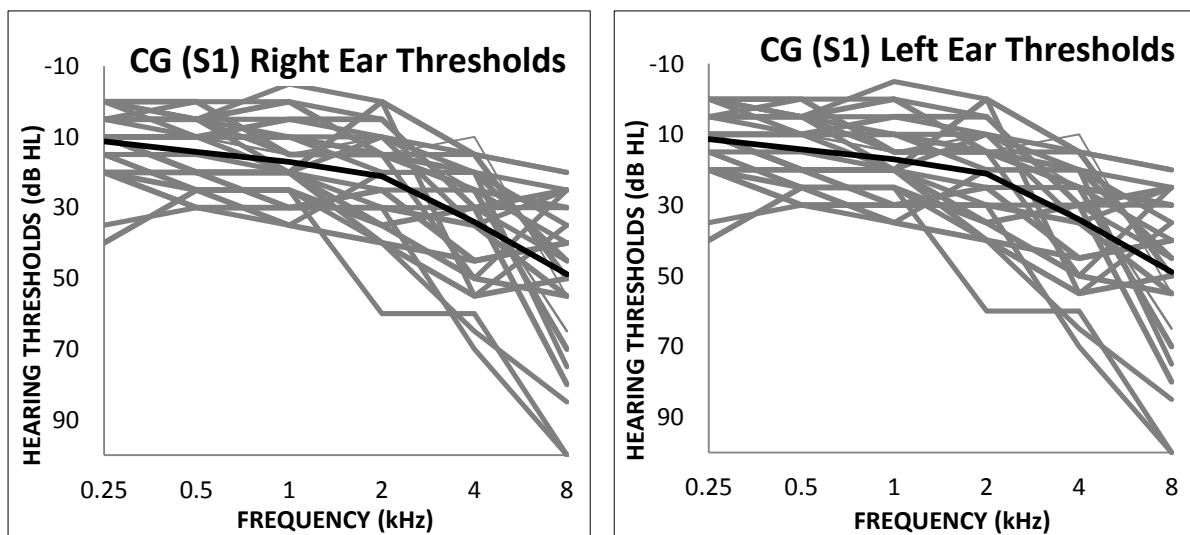


Figure 10. Hearing thresholds for the right and left ears of Control Group Session 1 only (CG (S1)) participants (n = 27). The dark line indicates the mean thresholds for that ear, while the light lines indicate individual participant thresholds.

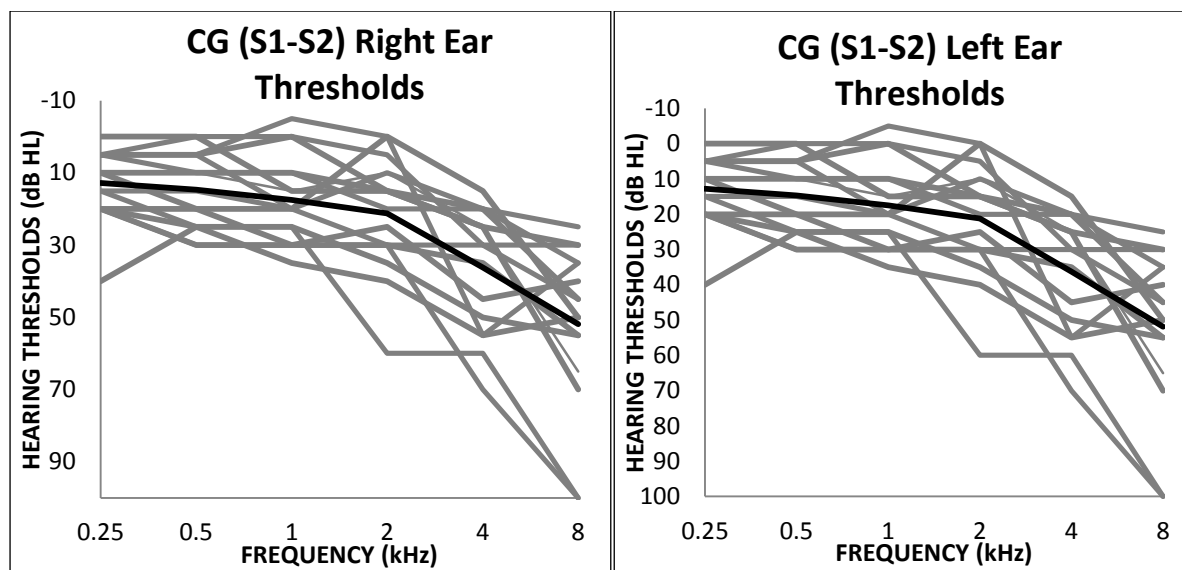


Figure 11. Hearing thresholds for the right and left ears of control group Session 1 and Session 2 (CG (S1-S2)) participants ($n = 16$). The dark line indicates the mean thresholds for that ear, while the light lines indicate individual participant thresholds.

4.1.4.3 The Normal Hearing Group

The hearing thresholds of the normal hearing group were obtained from audiograms obtained through either a research project that they had previously been involved in (McAuliffe & Sinex, in progress), or administered on the day that they completed the attention and memory tasks for the first time, as with the control group. To be included in the normal hearing group, participants had to present with thresholds ≤ 20 dB HL between 250 and 8000 Hz in both ears. On-going, non-intermittent tinnitus perception in either ear would also exclude them from the study. The hearing thresholds for all normal hearing group participants are shown in Figure 12.

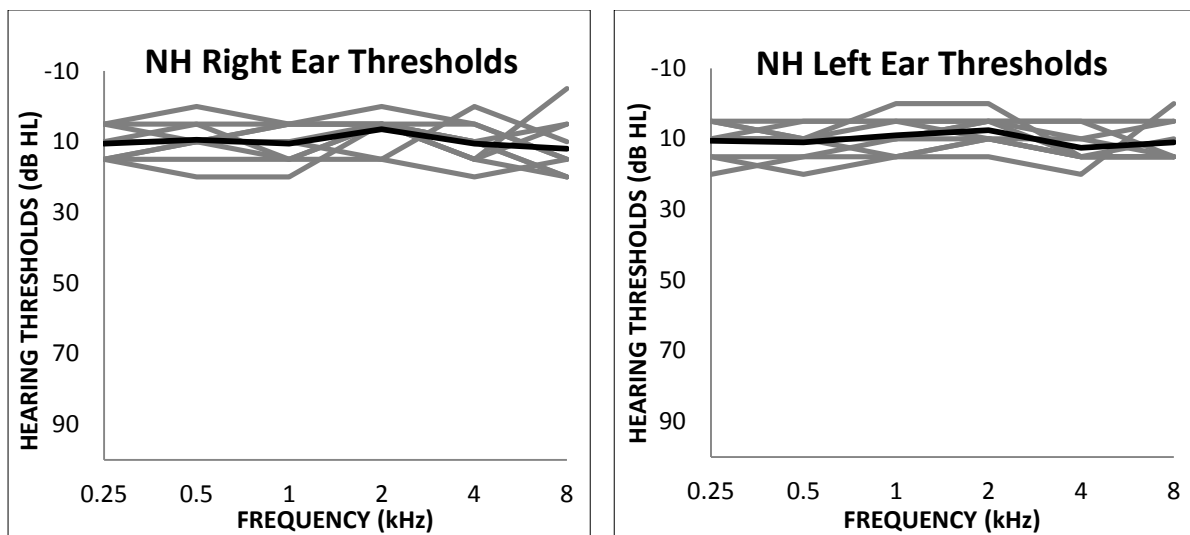


Figure 12. Hearing thresholds for the right and left ears of normal hearing (NH) group participants ($n = 10$). The dark line indicates the mean thresholds for that ear, while the light lines indicate individual participant thresholds.

4.1.4.4 Age and Hearing Loss

Hearing loss is related to age (Gates & Mills, 2005; see also Section 2.3.3.2). Figure 13 shows the four frequency pure-tone averages for all participants for the left and right ears separately, as compared with age. For this study, the four frequency pure-tone average used was the average threshold across the speech-dominant frequencies: 500, 1000, 2000 and 4000 Hz. It should be noted that one data point (the right ear pure-tone average for one participant in the experimental group, participant number 101) was not displayed on this graph, as the value = 116.25 dB HL due to the profound deafness for that ear, which resulted in a graphical outlier.

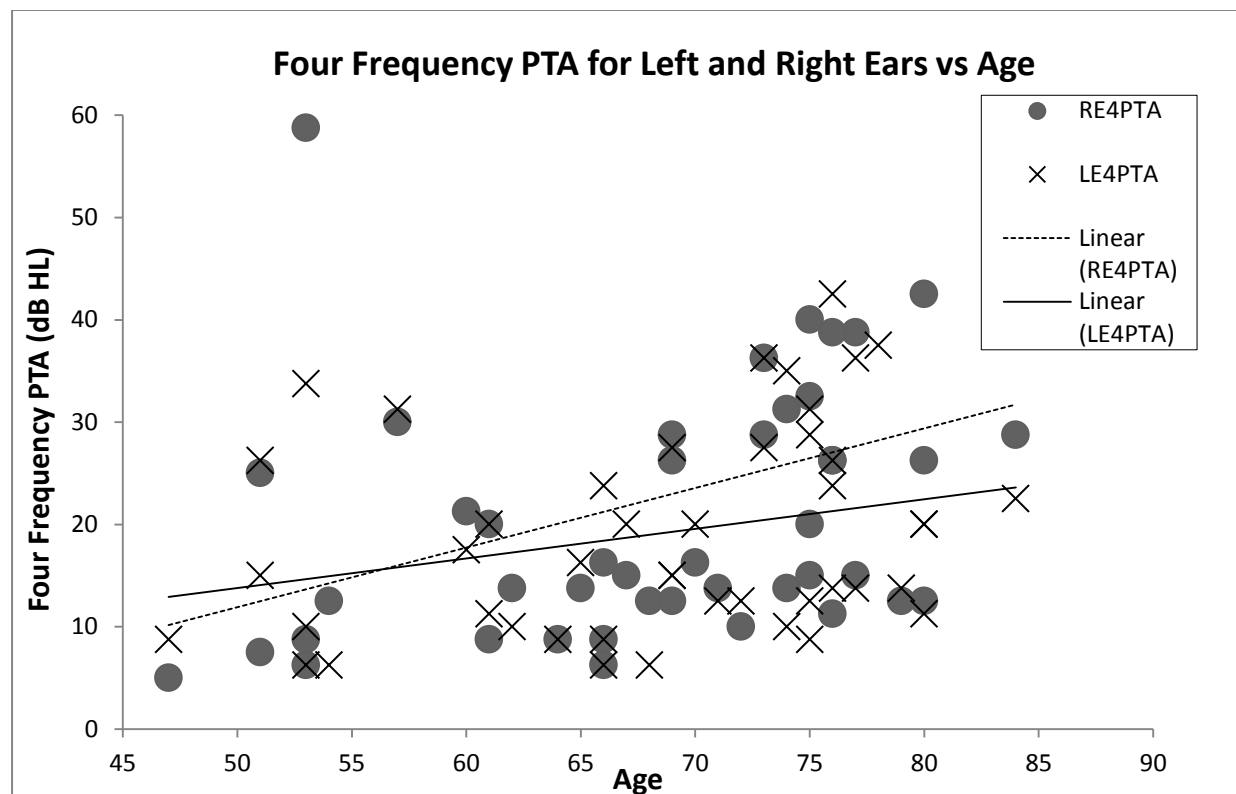


Figure 13. Four frequency pure-tone averages (PTA) for the left and right ears of all study participants with and without hearing loss ($n = 45$) compared with age. The four frequency pure-tone average is the mean of the individual's threshold at 500, 1000, 2000 and 4000 Hz. RE4PTA = the four frequency pure-tone average for the right ear, indicated by solid circles; while LE4PTA = the four frequency pure-tone average for the left ear, indicated by crosses. The dotted line is the right ear linear trend line, while the solid line is the left ear linear trend line.

4.1.4.5 Adjectives

As is the custom for categorising hearing loss in New Zealand, each participant's four frequency pure-tone average was calculated and from there a categorical descriptor (adjective) was assigned. This is based on the work of Goodman (1965). This data is shown in Tables 4 and 5. One participant in the experimental group, two in the control, and one in the normal hearing group had the same four frequency pure-tone average in both ears, so the calculation did not yield a "better ear".

Table 4. Number of participants in each group who had a four frequency pure-tone average of the stated categorical adjective. Also a count of the number of participants whose better ear based on their four frequency pure-tone average was the right ear. EG = Experimental Group, CG = Control Group and NH= Normal Hearing Group.

Right Ear	Better Ear?	Normal	Slight	Mild	Moderate	Moderately-Severe	Severe	Profound
EG (n = 8)	3	0	1	5	0	1	0	1
CG (n = 27)	8	11	6	9	1	0	0	0
NH (n = 10)	6	10	0	0	0	0	0	0

Table 5. Number of participants in each group who had a four frequency pure-tone average of the stated categorical adjective. Also a count of the number of participants whose better ear based on their four frequency pure-tone average was the left ear. EG = Experimental Group, CG = Control Group and NH= Normal Hearing Group

Left Ear	Better Ear?	Normal	Slight	Mild	Moderate	Moderately-Severe	Severe	Profound
EG (n = 8)	4	0	2	5	1	0	0	0
CG (n = 27)	17	12	8	7	0	0	0	0
NH (n = 10)	3	9	1	0	0	0	0	0

4.2 Experimental Group

The experimental group consisted of 8 participants, 4 males and 4 females. Their hearing loss profiles are detailed in Section 4.1.4.1. The participants were administered the Abbreviated Profile of Hearing Aid Benefit outcome measure and the Hearing Handicap Inventory for Adults questionnaire, and the auditory selective attention and working memory tasks. Participants were administered these assessments twice, prior to being fit with their new hearing aids and after at least 3 weeks of hearing aid use. All participants indicated no history of previous hearing aid use.

4.2.1 The Hearing Aids

The experimental group were all tested prior to receiving hearing aids, and following at least three weeks of hearing aid use. The characteristics of the hearing aids for these participants are presented in Table 6.

The brand of hearing aid fit varied across the experimental group participants. Two participants were fit with ReSound hearing aids, two were fit with Unitron, two were fit with Phonak, one participant was fit with Widex and one participant was fit with Starkey hearing aids. All participants received either ‘Receiver-in-the-Ear’ (RITE) aids ($n = 6$), or ‘Behind-the-Ear’ (BTE) ($n = 2$) aids. One participant was fit monaurally; all other participants were fit binaurally. The participant with the unilateral device had a profound loss in her unaided ear, which indicated little benefit from hearing aid use expected, given the level of loss and likelihood of cochlear ‘dead regions’.

Hearing aids are typically divided into different levels of technology. In Table 6, ‘elite’ is the top level available, followed by ‘advanced’, ‘active’ and ‘essential’ – the lowest technology rank. The fitting prescription used for all hearing aids was NAL-NL2. All participants chose to keep their hearing aids following the trial period. ‘S1-S2’ refers to the number of days between the first (S1) and the second (S2) data collection sessions, when participants were administered the auditory selective attention and working memory tasks. One participant (participant number 108) had a much longer

time between testing, as they were initially part of the control group, but two months later they opted to receive hearing aids. They agreed to be tested at the end of their hearing aid trial and were therefore ultimately allocated to the experimental group. ‘Use’ refers to the number of days the hearing aids were worn, which was the same as S1-S2 for all participants with the exception of participant 108, due to initial allocation to the control group.

Table 6. Characteristics of the hearing aids fit to the 8 experimental group participants. PPT = participant number; RITE = receiver in the ear style aid, BTE = behind the ear style aid; ‘TechLevel’ = the technology level of the hearing aid (elite, advanced, active and essential); ‘S1-S2’ = the number of days between sessions; and ‘Use’ refers to the number of days of hearing aid use.

PPT	Brand	Model	Style	Fitting	TechLevel	Prescription	S1-S2	Use
101	ReSound	LiNX ²	RITE	Monaural	Advanced	NAL-NL2	24	24
102	Unitron	Quantum 210	BTE	Binaural	Essential	NAL-NL2	21	21
103	Widex	ME5-m	RITE	Binaural	Active	NAL-NL2	29	29
104	Phonak	Audeo V50	RITE	Binaural	Advanced	NAL-NL2	21	21
105	Starkey	Halo i110	RITE	Binaural	Elite	NAL-NL2	28	28
106	ReSound	LiNX ²	RITE	Binaural	Elite	NAL-NL2	20	20
107	Unitron	MoxiFit 700	RITE	Binaural	Advanced	NAL-NL2	39	39
108	Phonak	Bolero V90	BTE	Binaural	Elite	NAL-NL2	112	34

4.2.2 Abbreviated Profile of Hearing Aid Benefit

As mentioned in Section 3.2.2.2, the Abbreviated Profile of Hearing Aid Benefit (APHAB) was administered prior-to hearing aid fitting. (referred to as the “Unaided” condition) and subsequent-to being fit, or experiencing aid wear for at least three weeks (referred to as the “Aided” condition). The APHAB uses four subscales measuring ease of communication, listening in background noise, reverberation and aversiveness to sounds. The difference in scores between the Unaided and Aided conditions was analysed.

Significant differences ($p < .01$) were observed for Ease of Communication, Background Noise, and the Global score, which is the combined total of three subscales (Ease of Communication, Background Noise, and Reverberation), as measured by Mann-Whitney U test, presented in Table 7.

Table 7. Comparison of unaided and aided scores for the Abbreviated Profile of Hearing Aid Benefit (APHAB) for each of the 8 experimental group participants (PPT). Global Score and all four subscales are compared. Mean scores and Mann-Whitney U (MWU) significance values are also included.

PPT	101	102	103	104	105	106	107	108	Mean	MWU
Global Score										
Unaided	36.11	29.72	71.28	51.28	40.94	63.72	44.22	33.39	46.33	U = 7.000 p = .003
Aided	15.67	16.33	43.67	14.56	37.56	29.56	9.28	4.17	21.35	
Ease of Communication										
Unaided	12.83	16.33	72.67	56.00	43.67	70.67	45.67	13.00	41.35	U = 9.000 p = .007
Aided	1.00	10.17	37.17	6.50	35.50	31.00	6.50	2.83	16.33	
Background Noise										
Unaided	54.00	41.67	74.67	60.33	62.33	58.17	49.67	56.00	57.10	U = 3.000 p = .001
Aided	33.00	20.50	52.00	12.33	43.83	18.50	14.50	8.67	25.42	
Reverberation										
Unaided	41.50	31.17	66.50	37.50	16.83	62.33	37.33	31.17	40.54	U = 16.000 p = .049
Aided	13.00	18.33	41.83	24.83	33.33	39.17	6.83	1.00	22.29	
Aversiveness of Sounds										
Unaided	14.67	10.50	22.83	58.17	26.86	41.50	29.50	1.00	25.63	U = 21.500 p = .146
Aided	56.00	8.33	45.83	27.00	31.33	74.67	29.50	20.67	36.67	

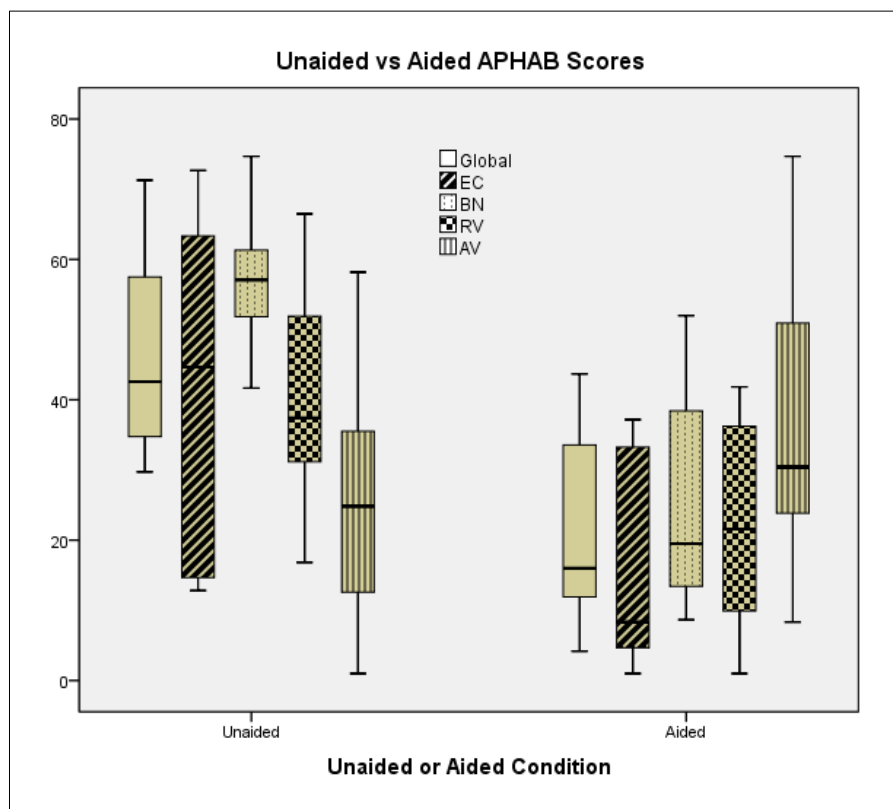


Figure 14. Boxplot displaying Abbreviated Profile of Hearing Aid Benefit (APHAB) scores before and after hearing aid fitting for experimental group participants (n = 8). Scores displayed are Global, Ease of Communication (EC), Background Noise (BN), Reverberation (RV), and Aversiveness of Sounds (AV). A lower score indicates less difficulty in specific listening situations. The middle line of each box represents the median value, while the extending lines represent the upper and lower extreme values for that variable.

4.2.3 Hearing Handicap Inventory for Adults

As detailed in Section 3.2.2.1 the Hearing Handicap Inventory for Adults (HHIA) is a self-assessment tool with 25 questions intended to measure the social and emotional effects of hearing loss on the participant (Newman et al., 1991). There are two subscales: *social*, which measures the disability experienced due to the hearing impairment in social situations, and *emotional*, which relates to how the participant feels about the situations where their hearing loss may cause difficulties.

A one-tailed Mann-Whitney U test was conducted to look for significant differences prior to and following hearing aid fit. Significant differences ($p < 0.01$) were observed for the emotional, social, and total scores. The total score is the combined score of the emotional and social subscales.

The author of the HHIA, Newman et al. (1991), recommend that as a guide for clinicians dealing with individual clients, a change in total score of at least 12 points is required to be clinically meaningful. This was observed for all participants except participant numbers 101 and 102.

Table 8. Comparison of aided and unaided scores for the Hearing Handicap Inventory for Adults for each of the 8 experimental group participants (PPT). The total score, as well as the emotional and social subscales scores are compared. Mean scores and Mann-Whitney U (MWU) significance values are also displayed.

PPT	101	102	103	104	105	106	107	108	Mean	MWU
Emotional										
Unaided	6	10	32	20	30	18	24	14	20.00	U = 7.500 p = .003
Aided	4	6	26	4	6	2	6	0	7.71	
Social										
Unaided	12	14	34	10	20	22	20	8	18.86	U = 6.500 p = .002
Aided	8	10	16	0	8	0	2	0	6.29	
Total										
Unaided	18	24	66	30	50	40	44	22	38.86	U = 5.000 p = .001
Aided	12	16	42	4	14	2	8	0	14.00	
Change	6	8	24	26	36	38	36	22	24.86	

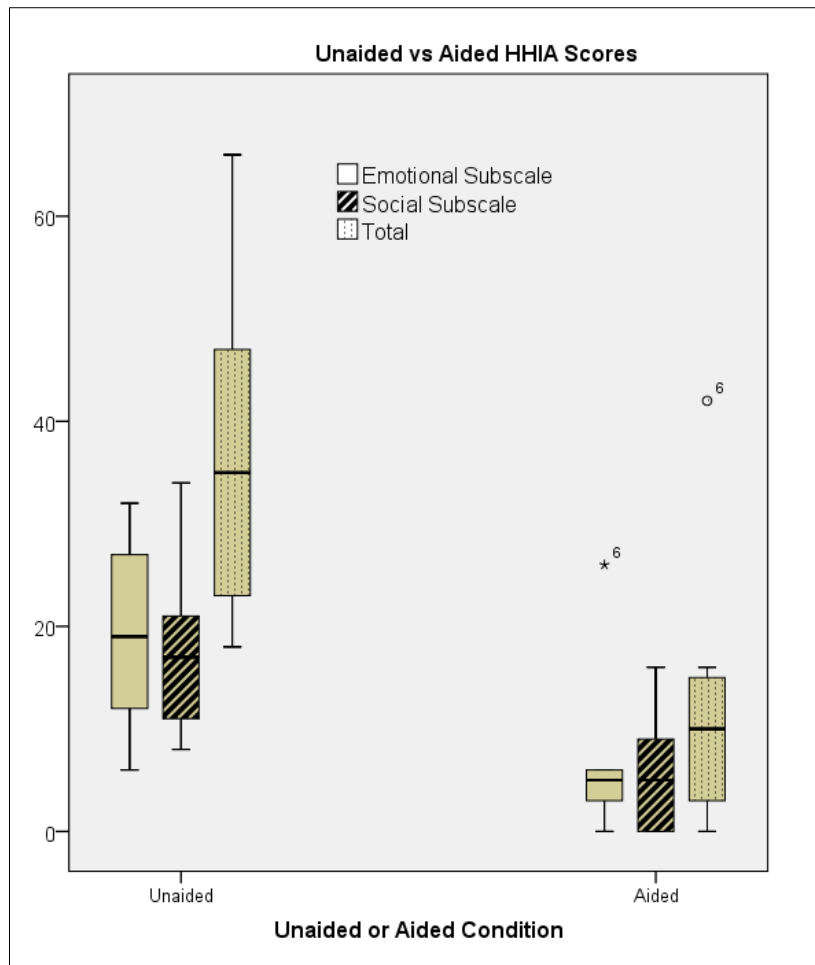


Figure 15. Boxplot displaying Hearing Handicap Inventory for Adults (HHIA) scores before and after hearing aid fitting for experimental group participants ($n = 8$). Scores displayed are calculated from the Emotional Subscale, Social Subscale and the combined Total score. A lower score indicates less difficulty in specific listening situations. The middle line of each box represents the median value, while the extending lines represent the upper and lower extreme values for that variable. The asterisk indicates an outlier, and the open circle indicates an extreme outlier.

4.3 Cognitive Test 1: Auditory Selective Attention Task (ASA)

This method assessed auditory selective attention. Data collected were overall percent correct; mean overall reaction time (RT); and the mean reaction time digit measure (RTD) or reaction time required for indicating the digit recalled for a response.

The overall percent correct refers to the percentage of correct responses obtained by a participant during the auditory selective attention task.

The overall mean reaction time (RT) refers to the mean length of time in milliseconds (ms) from the start of the trial until the participant registered their response, indicating which colour they heard the target speaker nominate via selecting a colour box, depicted in Figure 3.

The mean reaction time digit (RTD) refers to the mean length of time in milliseconds (ms) from the selection (i.e. click) of the colour box, until the selection of the digit box for the auditory selective attention task.

4.3.1 Aided versus Unaided

Regarding the experimental group, the auditory selective attention scores prior to hearing aid fitting was compared to the post-fitting score.

4.3.1.1 Overall Percent Correct

For five participants, there was an increase in percent correct. For three participants there was a decrease. The mean difference between the two sessions resulted in a decrease in percent correct by 0.78% with the mean percentage decrease calculated as 1.45%. The percentage difference was calculated via determining the mean of the two scores (S1 and S2) and dividing the raw difference between the two sessions by this number. This result was multiplied by 100 to gain the percentage difference.

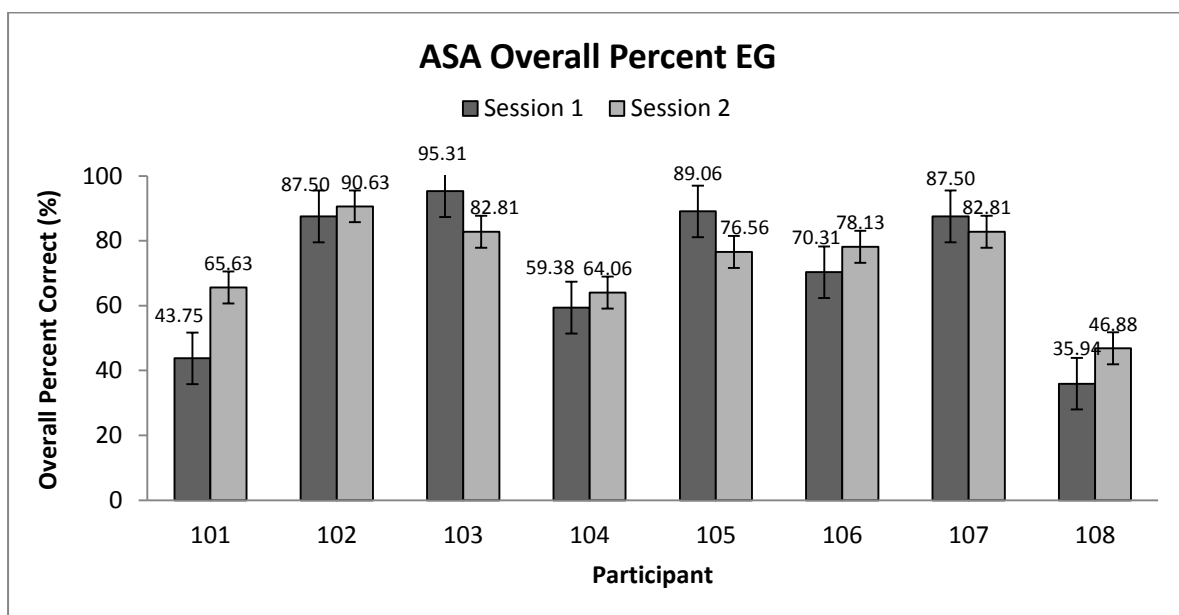


Figure 16. The auditory selective attention (ASA) overall percent correct for all individual participants in the experimental group (EG), (n = 8) prior to hearing aid fitting (dark grey = Session 1) and after hearing aid fitting (lighter grey = Session 2). The numbers represent the individual score for that session, while the error bars display the standard error for each participant.

The normal hearing group performed better than those control group participants tested at S1 and retested at S2 (i.e. CG (S1-S2)). The normal hearing group also performed better than the experimental group across both sessions (S1 or S2). To examine any potential learning effect, the mean score difference and the mean percentage difference were analysed. The normal hearing group and the experimental group had very similar small decreases in both mean score difference and mean percentage difference; suggesting no measurable effect of the hearing aid intervention. The control group revealed an increase in overall percent correct, which may have been skewed by two participants who increased their S2 percent correct scores by over 25% each. A one-tailed Mann-Whitney U test showed no significant changes between sessions for any of the groups observed.

Table 9. Comparison of means at S1 and S2 (S1-S2) for the experimental group (EG), control group (CG) and normal hearing group (NH) on the auditory selective attention (ASA) overall percent correct. The highlighted black rows indicate the potential presence of a possible learning effect.

ASA OVERALL PERCENT CORRECT	EG (n = 8)	CG (n = 16)	NH (n = 10)
Mean Overall Percent Correct Session 1	71.09	67.58	84.38
Mean Overall Percent Correct Session 2	73.44	72.64	83.60
Mean Overall Percent Correct (Session 1 + Session 2) /2	72.27	70.11	83.99
Mean Overall Percent Correct Standard Deviation	4.88	4.89	1.80
Mean Score Difference	-0.78	5.29	-0.78
Mean Percentage Difference	-1.45	8.19	-1.92
Mann-Whitney U value	31	112	48.5
Mann-Whitney U test p-value	0.468	.279	.462

4.3.1.2 Overall Reaction Time

For reaction time, measured decreases in latency were indicative of improvements as the participant had responded faster. This is in contrast to overall percent correct detailed in Section 4.3.1.1, with increases in values indicative of improvements. For all participants with the exception of one (participant 103), there was a decrease in reaction time. The mean difference between the two sessions was -732.78 ms and the mean percentage decrease was 18.9%. As compared to the rest of the experimental group, participant number 108, demonstrated a higher-than-average reaction time for the first session. A one tailed Mann-Whitney U test with the exclusion of the outlier showed no significant change comparing before fitting to post fitting reaction time. A one tailed Mann-Whitney U test with the inclusion of the outlier showed no significant change comparing before fitting to post fitting reaction time.

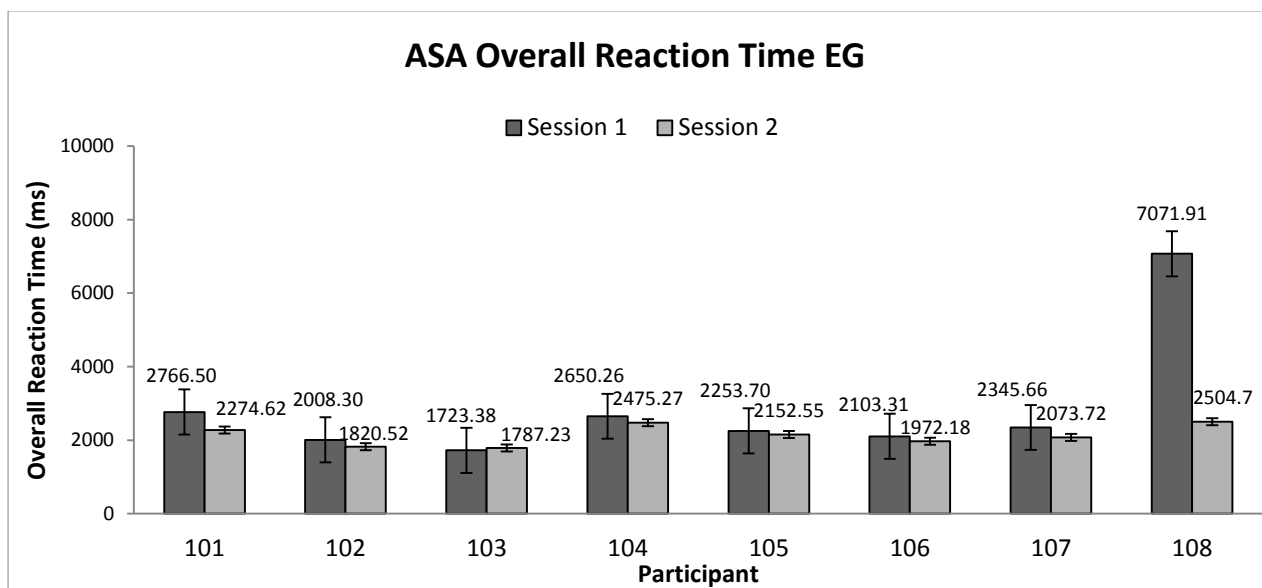


Figure 17. The auditory selective attention (ASA) overall reaction time for all individual participants in the experimental group (EG), ($n = 8$), prior to hearing aid fitting (dark grey = Session 1) and after hearing aid fitting (lighter grey = Session 2). The numbers represent the individual reaction time in milliseconds (ms) for that session, while the error bars display the standard error for each participant.

The normal hearing group and those control group participants tested at S1 and retested at S2 (S1-S2) (i.e. CG (S1-S2)), were also assessed for any potential procedural learning effect. Again, the normal hearing group on average, performed better than both the control group and experimental group for both sessions. To examine any potential learning effect, the mean score difference and the mean percentage difference were analysed. The normal hearing group only demonstrated a very small difference in overall reaction time between sessions, suggesting there was less learning effect present, compared with overall percent correct results. This suggests that improvements demonstrated by the experimental group could potentially be due to hearing aid intervention. A one-tailed Mann-Whitney U test showed no significant changes between sessions for any group.

Table 10. Comparison of means at S1 and S2 (S1-S2) for the experimental group (EG), control group (CG) and normal hearing group (NH) for auditory selective attention (ASA) overall reaction time (RT). The highlighted black rows indicate where a potential learning effect could possibly be observed. The outlier, participant number 108, has been excluded for one data column to illustrate the data with and without their inclusion. This is due to their extreme result possibly skewing the data.

ASA OVERALL REACTION TIME (RT)	EG (n = 8)	EG without 108	CG (n = 16)	NH (n = 10)
Mean Overall RT Session 1	2865.38	2264.44	3103.86	1722.03
Mean Overall RT Session 2	2132.60	2079.44	2835.40	1683.10
Mean Overall RT (Session 1 +Session 2) /2	2498.99	2171.94	2969.63	1702.56
Mean Overall RT Standard Deviation	374.37	101.62	224.44	44.46
Mean Overall RT Difference (ms)	-732.78	-185.00	-353.79	-38.927
Mean Percentage Difference	-18.90	-7.98	-9.87	-1.33
Mann-Whitney U value	22	17	99	46
Mann-Whitney U test p-value	0.164	0.191	0.144	0.398

4.3.1.3 Reaction Time Digit

The reaction time digit (RTD) prior to hearing aid fitting was compared to the post-fitting reaction time. For half of the participants there was a decrease in RTD, indicative of improvement or faster responses; and for the other half there was an increase in RTD. The mean difference in latency between the two sessions was -371 ms and the mean percentage decrease was 16.98%.

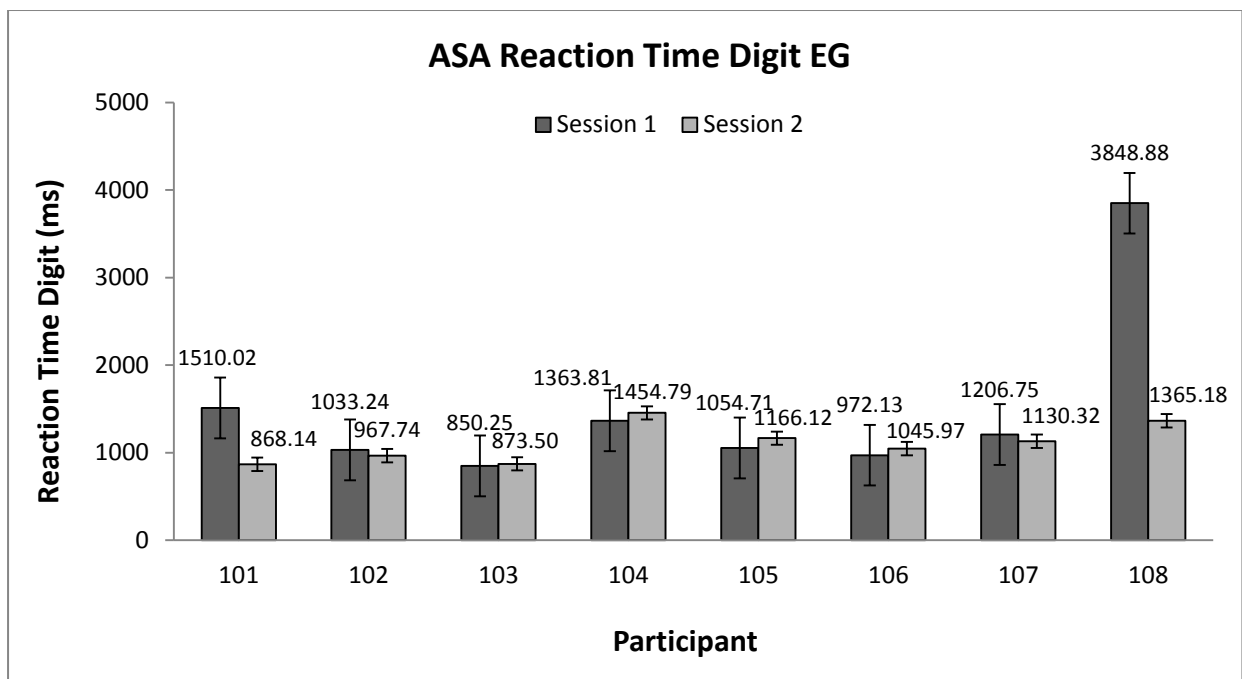


Figure 18. The auditory selective attention (ASA) reaction time digit for all individual participants in the experimental group (EG), ($n = 8$), prior to hearing aid fitting (dark grey = Session 1) and after hearing aid fitting (lighter grey = Session 2). The numbers represent the individual reaction time digit in milliseconds (ms) for that session, while the error bars display the standard error for each participant.

The normal hearing group and those control group participants tested at S1 were retested at S2 (S1-S2) (i.e. CG (S1-S2)) to determine if any potential procedural learning effect existed. To examine for any potential learning effect, the mean score difference and the mean percentage difference were analysed. The normal hearing group were observed to perform worse on average, for the second session; suggesting no procedural learning effect occurred. This implies that improvements observed for the experimental group may have been related to hearing aid intervention. A one-tailed Mann-Whitney U test showed no significant changes between sessions for the any of the three groups assessed.

Table 11. Comparison of means at S1 and S2 (S1-S2) for the experimental group (EG), control group (CG) and normal hearing group (NH) on the auditory selective attention (ASA) reaction time digit (RTD). The highlighted black rows indicate where a potential learning effect could possibly be observed.

ASA MEAN REACTION TIME DIGIT (RTD)	EG (n = 8)	CG (n = 16)	NH (n = 10)
Mean RTD Session 1	1479.97	1617.31	2112.42
Mean RTD Session 2	1108.97	1458.93	2199.72
Mean RTD (Session 1 +Session 2) /2	1294.47	1538.12	2156.07
Mean RTD Standard Deviation	222.94	142.43	72.25
Mean RTD Difference (ms)	-371.00	-207.05	87.30
Mean Percentage Difference	-16.98	-9.13	3.01
Mann-Whitney U value	26	111	48
Mann-Whitney U test p-value	0.287	0.270	0.456

4.3.2 Hearing Impaired versus Normal Hearing

ASA scores from the first session were compared to look at difference between all participants with hearing impairment: experimental group ($n = 8$) + control group (S1) ($n = 27$) for combined total of those demonstrating hearing loss ($n = 35$), contrasted against those with normal hearing ($n = 10$).

4.3.2.1 Overall Percent Correct

Figure 19 demonstrates that there was a much larger range of ASA scores for the participants with hearing impairment. On average, these participants performed worse than the normal hearing group.

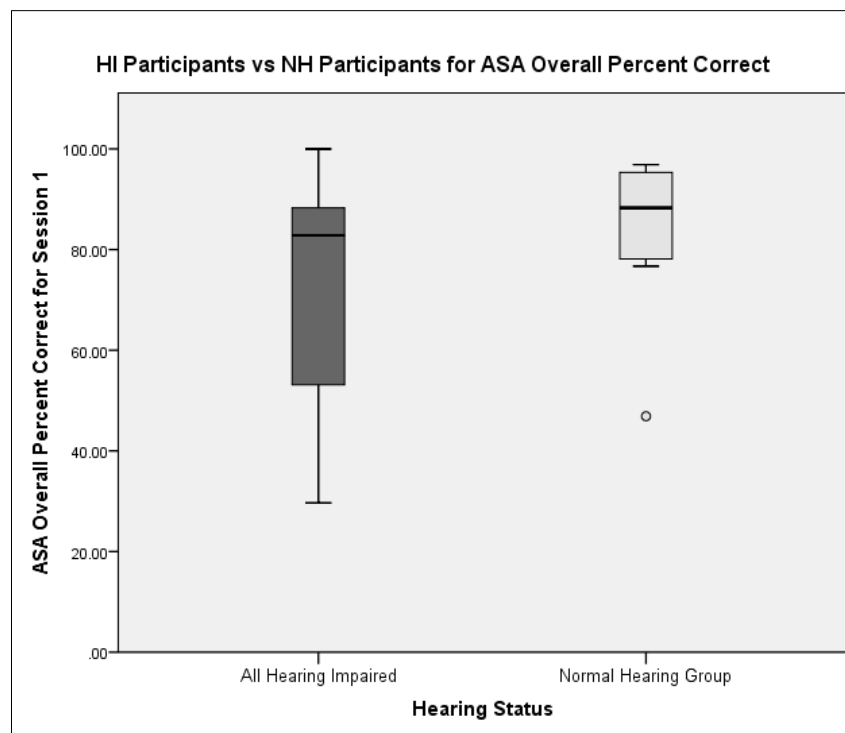


Figure 19. Comparison of first session (S1) overall percent correct scores for all participants with hearing impairment (HI) versus the normal hearing group (NH) participants for the auditory selective attention task (ASA). The dark grey box represents the hearing impaired participants ($n = 35$) while the light grey box represents the normal hearing group ($n = 10$). The middle line of each box represents the median value, while the extending lines represent the upper and lower extreme values for that variable. The open circle indicates an outlier.

4.3.2.2 Overall Reaction Time

Figure 20 demonstrates that there was a similar range for overall ASA reaction time for the hearing impaired participants compared to the normal hearing group.

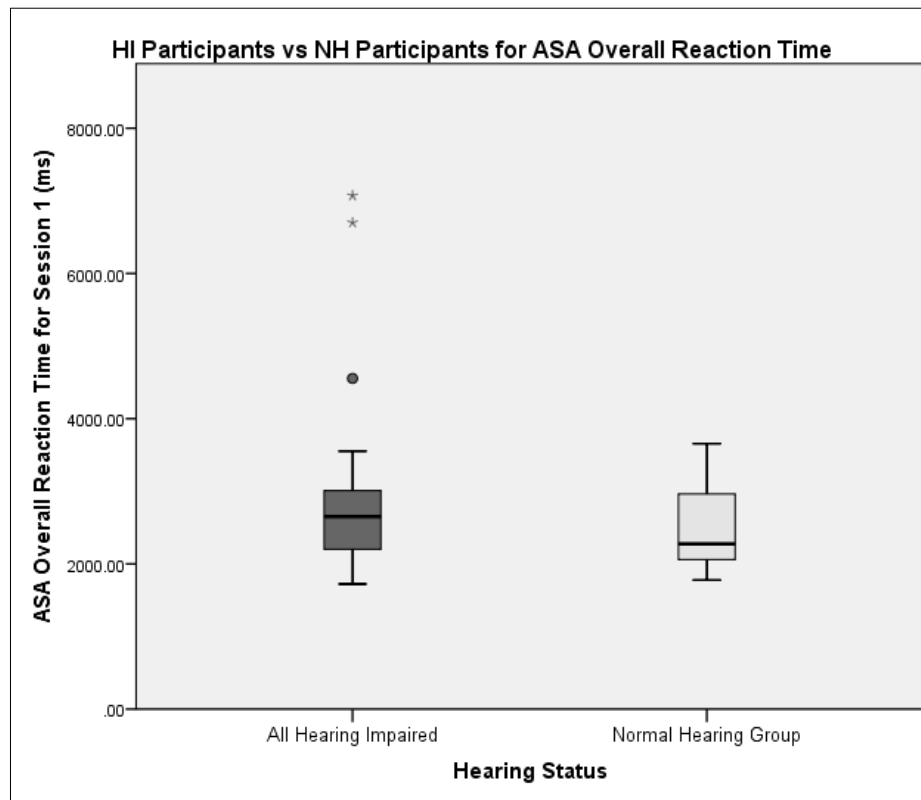


Figure 20. Comparison of first session (S1) overall reaction time in milliseconds (ms) for all participants with hearing impairment (HI) versus the normal hearing group (NH) participants for the auditory selective attention task (ASA). The dark grey box represents the hearing impaired participants ($n = 35$) while the light grey box represents the normal hearing group ($n = 10$). The middle line of each box represents the median value, while the extending lines represent the upper and lower extreme values for that variable. The asterisks represent outliers while the shaded circle represents a suspected outlier.

4.3.2.3 Reaction Time Digit

Figure 21 demonstrates that there was a similar range for overall reaction time for the hearing impaired participants compared to the normal hearing group.

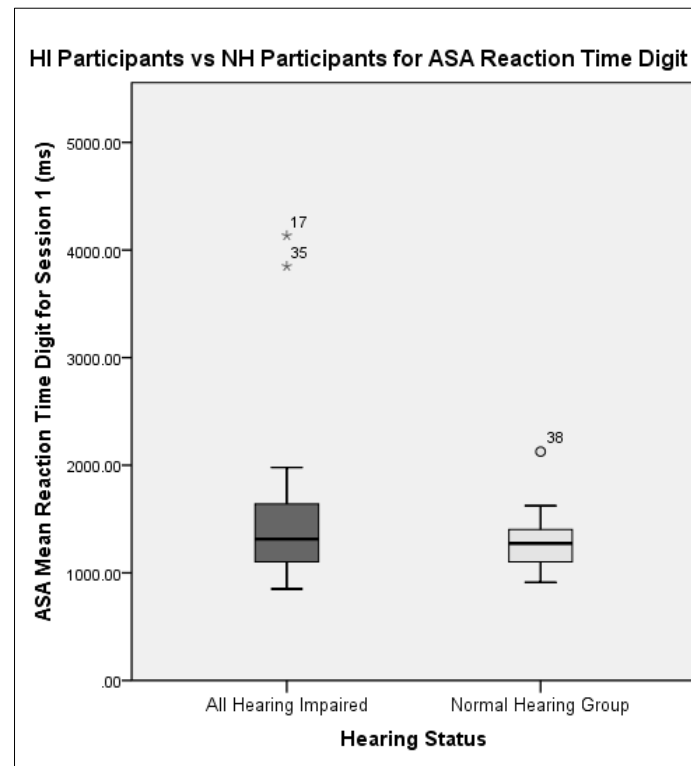


Figure 21. Comparison of first session (S1) reaction time digit in milliseconds (ms) for all participants with hearing impairment (HI) versus the normal hearing group (NH) participants for the auditory selective attention task (ASA). The dark grey box represents the hearing impaired participants ($n = 35$) while the light grey box represents the normal hearing group ($n = 10$). The middle line of each box represents the median value, while the extending lines represent the upper and lower extreme values for that variable. The asterisks indicate extreme outliers while the open circle indicates an outlier.

4.3.3 Relationship between Hearing Loss Severity and Cognition

As described in Section 2.3.3.2, hearing loss severity is anticipated to increase with age. As per Section 2.1.3, cognitive abilities are anticipated to decline with age. The following section investigates findings potentially associated with these theorised relationships.

4.3.3.1 Correlations

Table 12 shows the results of one-tailed Spearman correlations for the variables of: age, ASA overall percent correct (% Correct), ASA overall mean reaction time (Mean RT), ASA mean reaction time digit (Mean RTD), right ear four frequency pure-tone average (RE4PTA), and left ear four frequency pure-tone average (LE4PTA). Based on the prevailing research literature e.g., Lin (2011) and Lin et al. (2013), it was expected that hearing loss would be correlated with deficits in attention, as measured by the auditory selective attention task. This was observed via the negative correlation between ASA overall percent correct and RE4PTA ($r_s(43) = -.469, p = .001$) and ASA overall percent correct and LE4PTA ($r_s(43) = -.438, p = .001$). This suggested that as overall percent correct increased, pure-tone average decreased, and thus associated with better hearing.

Further, ASA Mean RT was positively correlated with RE4PTA ($r_s(43) = .270, p = .036$) and also with LE4PTA ($r_s(43) = .304, p = .021$). This suggested that as reaction time increased (i.e. the participant was slower and therefore worse at the task) pure-tone average increased and was therefore associated with worse hearing.

Table 12. Correlation matrix between auditory selective attention (ASA) measures and hearing loss. The scores displayed are overall percent correct (ASA % Correct); mean overall reaction time (ASA Mean RT); mean overall reaction time digit (ASA Mean RTD); left ear four frequency pure-tone average (LE4PTA); right ear four frequency pure-tone average (RE4PTA); and age.

	1	2	3	4	5	6
1 Age	1.00	.300*	.460**	-.411**	.358**	.380**
2 LE4PTA		1.00	.858**	-.438**	.304*	.202
3 RE4PTA			1.00	-.469**	.270*	.232
4 ASA % Correct				1.00	-.606**	-.586**
5 ASA Mean RT					1.00	.891**
6 ASA Mean RTD						1.00

*. Correlation was significant at the 0.05 level (1-tailed).

**. Correlation was significant at the 0.01 level (1-tailed).

4.3.3.2 Overall Percent Correct

Figure 22 shows a relationship between overall percent correct and age. Older participants tended to perform more poorly on this aspect of the auditory selective attention task. Similar results were found for age and overall mean reaction time for the auditory selective attention task ($r_s(43) = .358, p = 0.008$) and mean reaction time digit ($r_s(43) = .380, p = .005$).

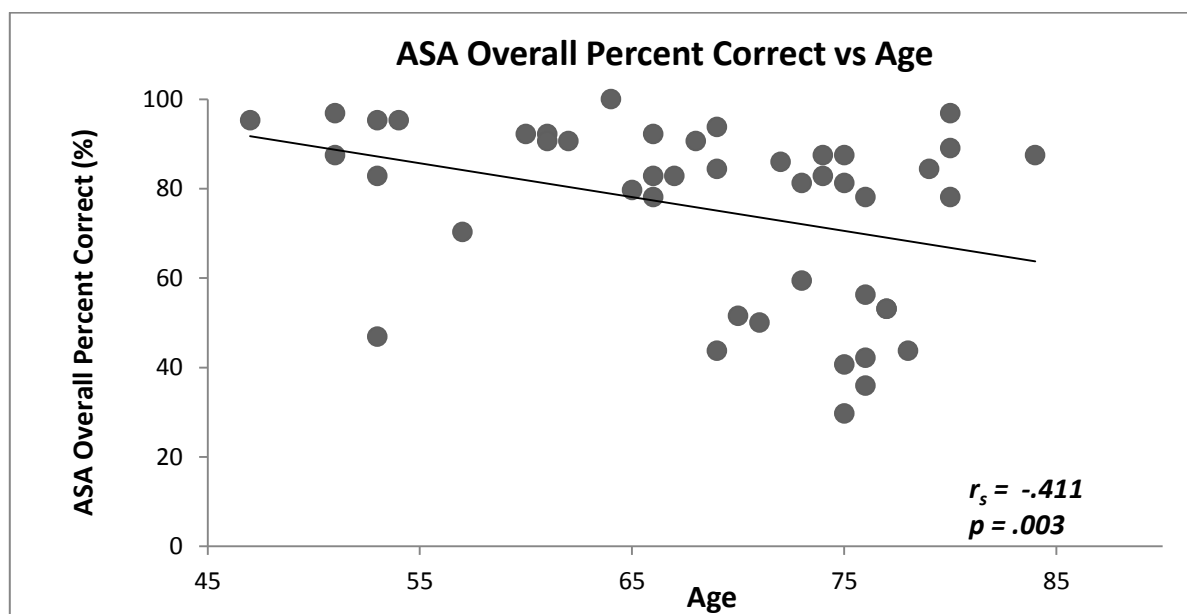


Figure 22. Relationship between age and first session overall percent correct scores for all study participants ($n = 45$), those with ($n = 35$) and without ($n = 10$) hearing loss, for the auditory selective attention task (ASA). The solid circles indicate the individual's score. The line indicates the linear trend line showing a decrease in overall percent correct as age increases.

As age is related to both hearing loss and cognition, some form of relationship between hearing loss and cognition was anticipated. This was observed. As per Figure 23, it was clear that as the severity of the LE4PTA increased, the overall percent correct for the auditory selective attention task decreased ($r_s(43) = -.438$, $p = .001$). A similar significant relationship between RE4PTA and overall percent correct was observed ($r_s(43) = -.469$, $p = .001$) (see Figure 24).

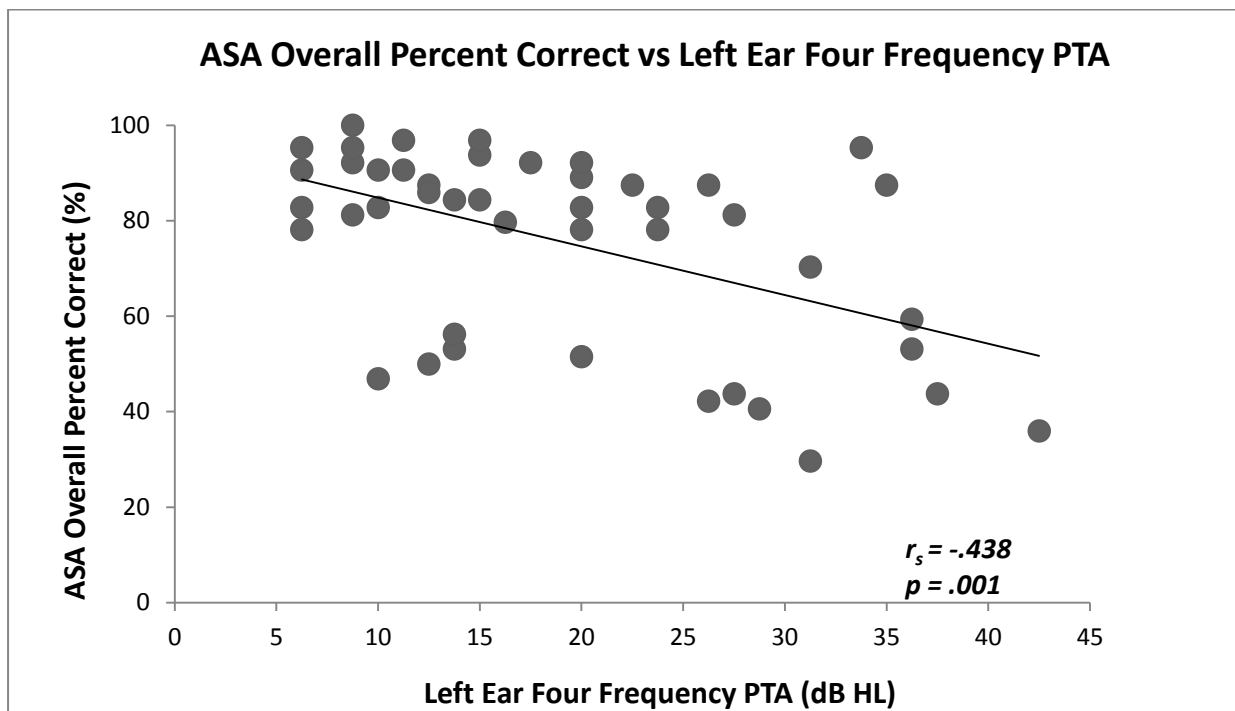


Figure 23. Relationship between left ear four frequency pure-tone average (PTA) and first session (S1) overall percent correct scores for all study participants ($n = 45$), those with ($n = 35$) and without ($n = 10$) hearing loss, for the auditory selective attention task (ASA). The solid circles indicate the individual's score. The line indicates the linear trend line showing a decrease in overall percent correct as left ear four frequency pure-tone average increases.

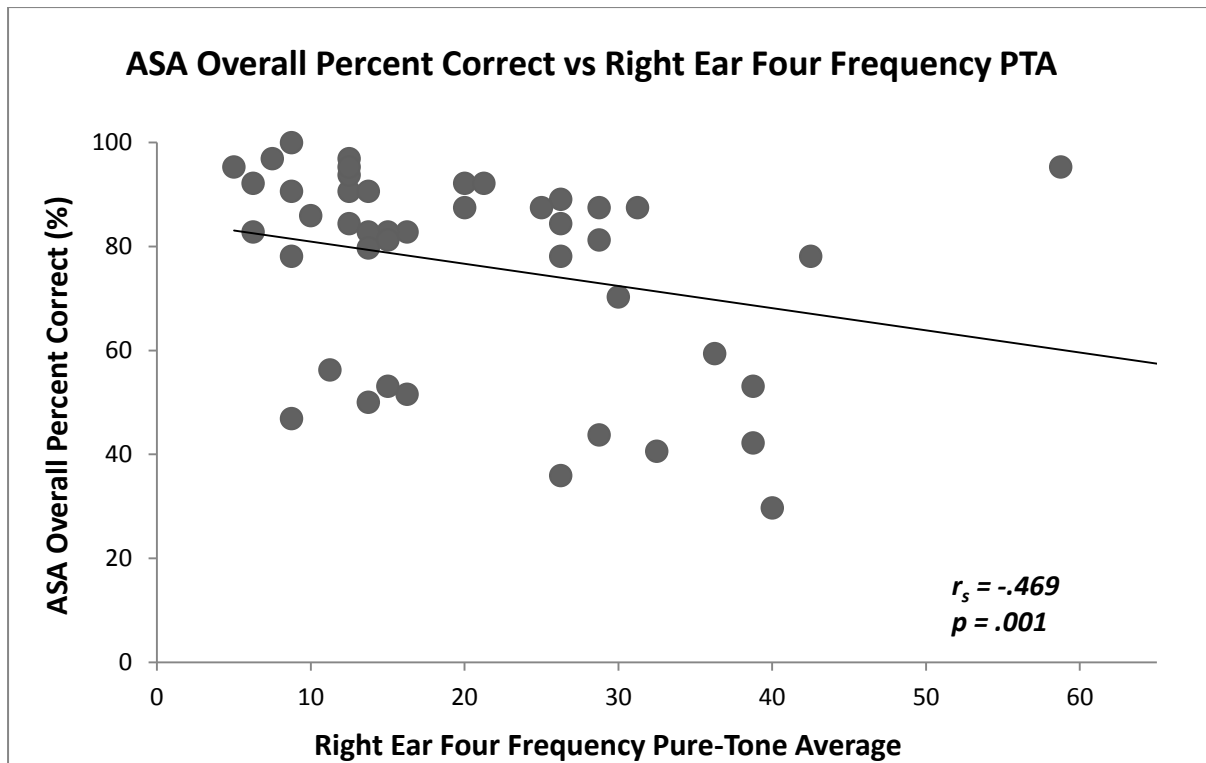


Figure 24. Relationship between right ear four frequency pure-tone average (PTA) and first session (S1) overall percent correct scores for all study participants ($n = 45$), those with ($n = 35$) and without ($n = 10$) hearing loss, for the auditory selective attention task (ASA). The solid circles indicate the individual's score. The line indicates the linear trend line showing a decrease in overall percent correct as right ear four frequency pure-tone average increases. The different x-axis scale should be noted when comparing to Figure 23). Also it should be noted that one participant (participant number 101) with a right ear four frequency PTA of 116.25 and an overall percent correct score of 43.75, was excluded from the figure presentation, although was included in the r and p value calculations.

4.3.3.3 Overall Reaction Time

Figure 25 shows that as reaction time increased (participants registered responses more slowly and were therefore worse at the task), pure-tone average for the left ear also increased. This suggested a potential relationship between hearing loss and reaction time ($r_s(43) = .304, p = .021$). There was a similar significant correlation between right ear four frequency pure-tone average and mean overall reaction time ($r_s(43) = .270, p = .036$).

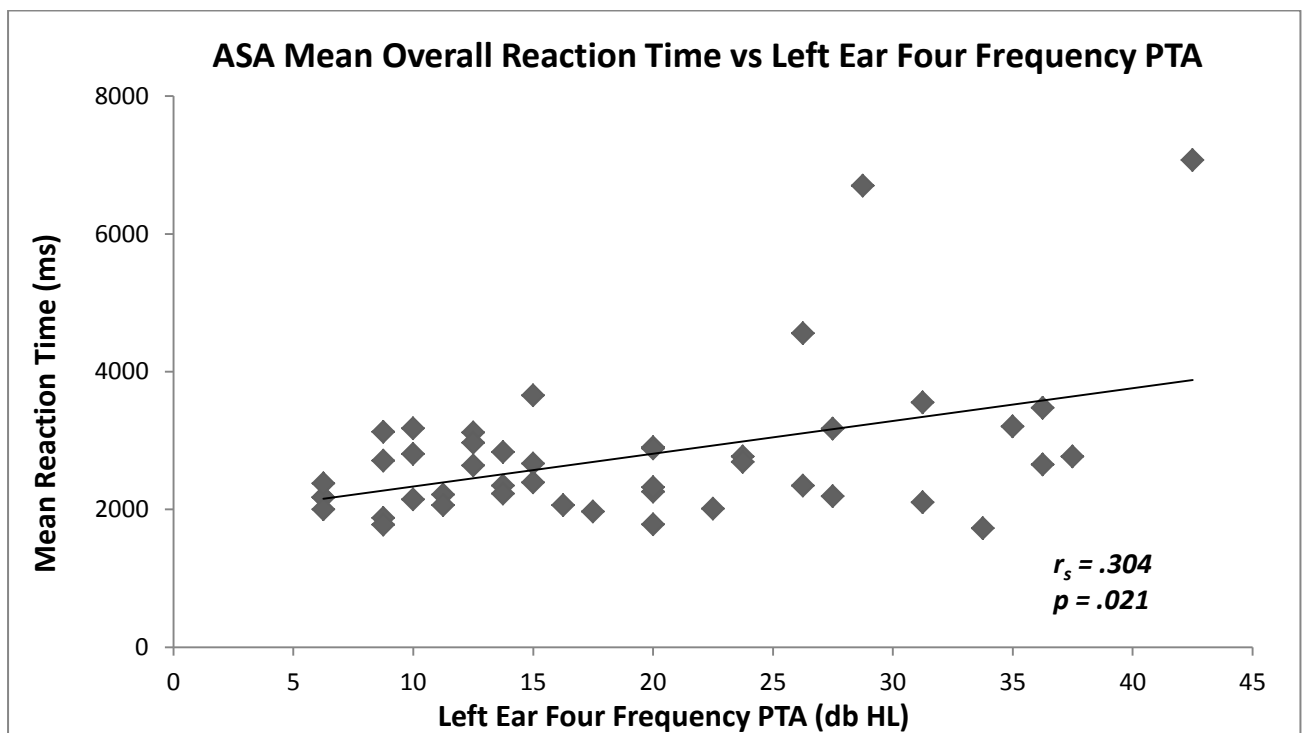


Figure 25. Relationship between left ear four frequency pure-tone average (PTA) and first session overall reaction time in milliseconds (ms) for all study participants ($n = 45$), those with ($n = 35$) and without ($n = 10$) hearing loss, for the auditory selective attention task (ASA). The solid diamonds indicate the individual's reaction time. The line indicates the linear trend showing an increase in reaction time (therefore the participant was slower) as left ear four frequency pure-tone average increases.

4.3.3.4 Reaction Time Digit

Figure 26 shows that as mean reaction time digit (RTD) increased (i.e. participants responded more slowly and were therefore worse at the task), pure-tone average for the left ear also increased. This was found to be almost statistically significant as measured by Spearman's rho ($r_s(43) = .202, p = .091$). A Pearson product movement correlation however did find a significant relationship ($r(43) = .369, p = .006$) but should be viewed with caution, given the sample not being normally-distributed. However, the above could suggest evidence for a potential relationship between hearing loss and RTD. Further, there was a correlation between right ear four frequency pure-tone average and RTD which appeared to be trending toward significance ($r_s(43) = .232, p = .062$). Possibly with a larger sample size, these results would have reached statistical significance. Figure 26 includes data from all participants with hearing loss (the control and experimental groups) as measured at Session 1 (S1).

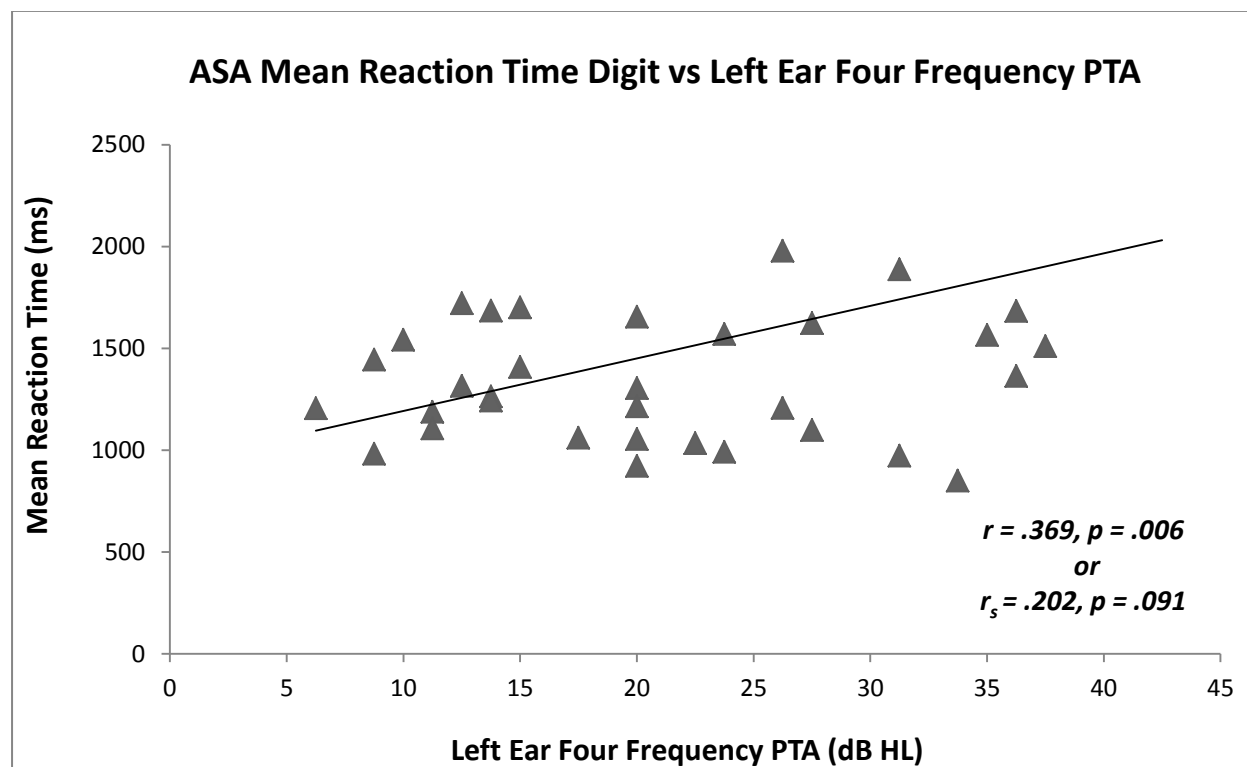


Figure 26. Relationship between left ear four frequency pure-tone average (PTA) and first session reaction time digit in milliseconds (ms) for all participants ($n = 35$) with hearing loss, experimental group ($n = 8$) and control group ($n = 27$), for the auditory selective attention task (ASA). The solid triangles indicate the individual's RTD. The line indicates the linear trend showing an increase in RTD (therefore the participant was slower) as left ear four frequency pure-tone average increases.

4.3.4 Further Testing with Matched Participants

By using a control group, this study aimed to look at the differences between the experimental group and the control group at Session 1 versus at Session 2, and also conduct pre- and post- measures to look for improvements due to intervention and any potential learning effect. An analysis of variance model (ANOVA) and partial correlation testing was conducted to test for these differences. To do this, the outlier participants in the experimental group had to be removed, and participants from control group (S1-S2) matched to those remaining in the experimental group, to create two equally sized and matched groups. The experimental group consisted of 6 participants, as participant 101 was removed due to the unusual hearing loss (see Section 4.1.4.1) and participant 108 was removed due to the different methodology (see Section 3.3.1) and also the unusual auditory selection attention reaction time scores at S1 (see Section 4.3.1.2 or 4.3.1.3). Thus, the number of participants in the experimental group included in this analysis was 6. The control group participants were matched first by considering hearing loss, as the focus of this research was the relationship between hearing loss and cognition. Sex and age demographic data was considered where required. The participant demographic and hearing loss data is presented in Table 13.

Table 13 Age and hearing loss data for the experimental group (EG) without outliers and the matched control group (CG) used for statistical analyses. 4PTA = four frequency pure-tone average, which is listed for the left ear (LE4PTA), right ear (RE4PTA), better ear (BE4PTA) and worse ear (WE4PTA). Age values are given in years; months. Hearing loss values are rounded to the nearest whole number, and given in dB HL.

	EG with No Outliers	Matched CG
Number of Participants	6	6
Males: Females	3:3	4:2
Mean Age	66;4	73;2
Standard Deviation	13;2	4;7
Age Range	51-84	66-80
LE4PTA Mean	28	26
RE4PTA Mean	34	33
BE4PTAMean	28	27
WE4PTAMean	35	36

4.3.4.1 ANOVA: Overall Percent Correct

A mixed-design analysis of variance was conducted to look for differences between the experimental group and the control group, and also for differences between Session 1 and Session 2 for the auditory selective attention task Overall Percent Correct. However there was not homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > .05$). The data was transformed (square root (highest score + 1 – individual score)) which ensured that there was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > .05$). Scores were normally distributed for both groups at both sessions, as assessed by Shapiro-Wilk's test ($p > .05$). There was homogeneity of covariances, as assessed by Box's test of quality of covariance matrices ($p = .486$).

There was no statistically significant group and session interaction for ASA Overall Percent Correct, $F(1,10) = 1.128$, $p = .313$, partial $\eta^2 = .101$. This means that ASA Overall Percent Correct scores did not significantly differ between the experimental and control group.

There was no statistically significant difference in ASA Overall Percent Correct between the experimental and control groups $F(1, 10) = 2.937$, $p = .117$, partial $\eta^2 = .227$.

4.3.4.2 ANOVA: Overall Mean Reaction Time

A mixed-design analysis of variance was conducted to look for differences between the experimental group and the control group, and also for differences between Session 1 and Session 2 for the auditory selective attention task Overall Mean Reaction Time.

Overall Mean Reaction Time scores were normally distributed for both groups at both sessions, as assessed by Shapiro-Wilk's test ($p > .05$). There was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > .05$). There was homogeneity of covariances, as assessed by Box's test of quality of covariance matrices ($p = .004$).

There was no statistically significant group and session interaction for ASA Overall Mean Reaction Time, $F(1,10) = .155, p = .702$, partial $\eta^2 = .015$. This means that ASA Overall Mean Reaction Time scores did not significantly differ between the experimental and control group.

There was a statistically significant difference in ASA Overall Mean Reaction Time between the experimental and control groups $F(1, 10) = 6.133, p = .033$, partial $\eta^2 = .380$.

4.3.4.3 ANOVA: Mean Reaction Time Digit

A mixed-design analysis of variance was conducted to look for differences between the experimental group and the control group, and also for differences between Session 1 and Session 2 for the auditory selective attention task Mean Reaction Time Digit.

Mean Reaction Time Digit scores were normally distributed for both groups at both sessions, as assessed by Shapiro-Wilk's test ($p > .05$). There was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > .05$). There was homogeneity of covariances, as assessed by Box's test of quality of covariance matrices ($p = .047$).

There was no statistically significant group and session interaction for ASA Mean Reaction Time Digit, $F(1,10) = .002, p = .967$, partial $\eta^2 = .000$. This means that ASA Mean Reaction Time Digit scores did not significantly differ between the experimental and control group.

There was a statistically significant difference in ASA Mean Reaction Time Digit between the experimental and control groups, $F(1, 10) = 5.232, p = .045$, partial $\eta^2 = .343$.

4.3.4.4 Post-hoc Power Analysis

Post-hoc power analysis revealed the study was underpowered for investigating potential interaction(s) between participant groups and the sessions generating measures of ASA, as per the mixed-model ANOVA. Power was calculated as 0.555 (55.5%) for Overall Percent Correct, 0.121 (12.1%) for Mean Reaction Time, and 0.055 (5.5%) for Reaction Time Digit.

4.3.4.5 Partial Correlations

Matched data as explained in Section 4.3.4 was subjected to a partial correlation in order to explore the relationship between hearing loss and auditory selective task measures while controlling for the effect of age.

The correlation between ASA Overall Percent Correct and LE4PTA was found to be statistically significant, ($r(9) = -.527$, $p = .048$), indicating that a relationship between auditory selective attention as indexed by the ASA task and hearing loss exists above and beyond the effects of age. The correlation between ASA Overall Percent Correct and RE4PTA when controlling for age was found to not be statistically significant, ($r(9) = -.125$, $p = .357$).

The correlation between ASA Overall Reaction Time and LE4PTA when controlling for age was found to not be statistically significant, ($r(9) = .286$, $p = .197$). Similarly, the correlation between ASA Overall Reaction Time and RE4PTA when controlling for age was found to not be statistically significant, ($r(9) = .363$, $p = .136$).

The correlation between ASA Reaction Time Digit and LE4PTA when controlling for age was found not to be statistically significant, ($r(9) = -.134$, $p = .347$). The correlation between ASA Reaction Time Digit and RE4PTA when controlling for age was also found not to be statistically significant, ($r(9) = -.307$, $p = .179$).

4.4 Cognitive Test 2: Digit Span Task (DS)

The digit span (DS) method employed assessed working memory. Data collected was: Forward two-error maximum; forward maximum length; backward two-error maximum; and backward maximum length. For all digit span measures, positive values were indicative of improvement (more digits recalled), in contrast to auditory selective attention task reaction times, which used decreases (less response time required) as indication of improvement.

The forward two-error maximum refers to the maximum number of digits able to be correctly recalled in forward order, before the participant made two errors. The forward maximum length is the maximum numbers a participant can recall in forward order. The backward two-error maximum refers to the maximum number of digits able to be correctly recalled in backward order, before the participant made two errors. The backward maximum length was the maximum numbers a participant recalled in backward order. This is described more fully in Section 3.2.2.4

4.4.1 Aided versus Unaided

For the experimental group, digit span scores obtained prior to hearing aid fitting were compared to the post-fitting scores.

4.4.1.1 Forward Two-Error Maximum

Three experimental group participants improved their scores, two participants decreased their scores, and the remaining three participants scored the same for both sessions (see Figure 27). The mean difference between the two sessions was an increase of 0.38, and the mean percentage increase was 5.68%.

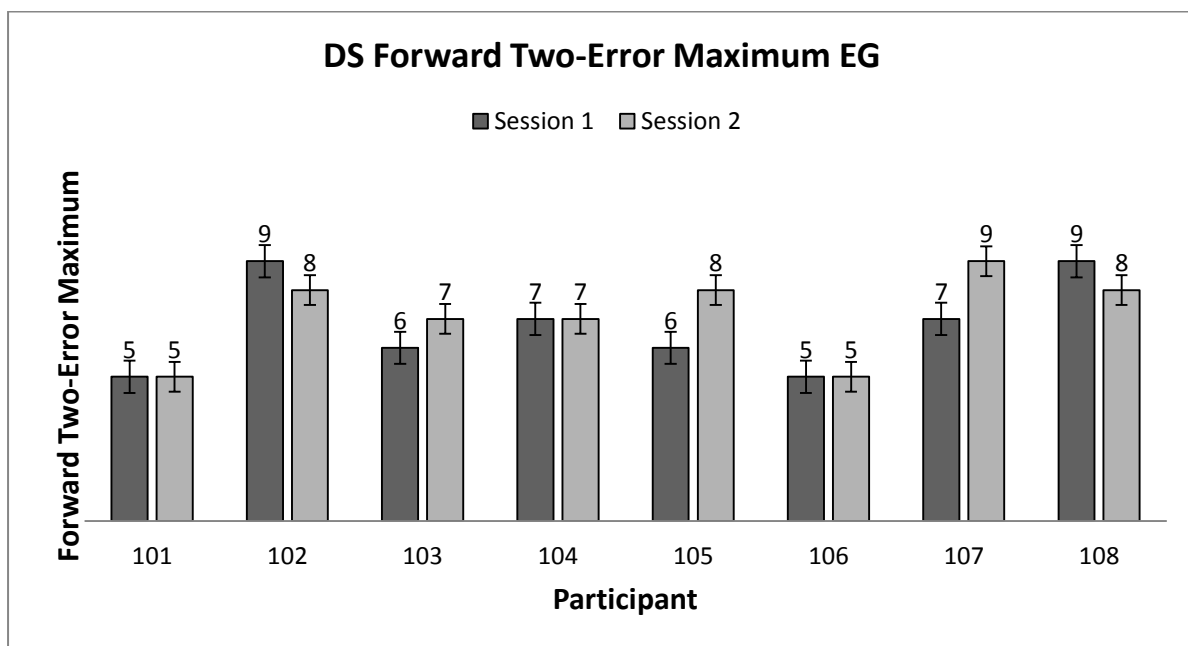


Figure 27. The digit span (DS) forward two-error maximum for all individual participants ($n = 8$) in the experimental group (EG), prior to hearing aid fitting (dark grey = Session 1) and after hearing aid fitting (lighter grey = Session 2). The numbers represent the individual score for that session, while the error bars display the standard error for each participant.

Digit span forward two-error maximum results from the normal hearing participants and those control group participants tested at S1 and retested at S2 (i.e. CG (S1-S2)), were analysed to account for any potential procedural learning effect. The normal hearing group performed worse than the control and experimental groups for S1. However, the normal hearing group showed the greatest increase in mean digit span, as compared to the control and experimental groups. This suggests that digit span improvements, especially for this group, were potentially due to a learning effect. One-tailed Mann-Whitney U testing revealed no significant changes between sessions for any of the three groups assessed.

Table 14. Comparison of means at S1 and S2 (S1-S2) for the experimental group (EG), control group (CG) and normal hearing group (NH) on the digit span (DS) forward two-error maximum. The highlighted black rows indicate scores for which a potential learning effect could possibly be observed.

DS FORWARD TWO-ERROR MAXIMUM	EG (n = 8)	CG (n = 16)	NH (n = 10)
Mean Forward Two-Error Maximum Session 1	6.75	6.69	5.90
Mean Forward Two-Error Maximum Session 2	7.13	6.69	6.70
Mean Forward Two-Error Maximum (Session 1 + Session 2)/2	6.94	6.69	6.30
Mean Forward Two-Error Maximum Standard Deviation	0.44	0.25	0.80
Mean Score Difference	0.38	0.00	0.80
Mean Percentage Difference	5.68	-0.13	11.54
Mann-Whitney U value	27	117.5	33
Mann-Whitney U test p-value	0.306	0.349	0.098

4.4.1.2 Forward Maximum Length

Two participants improved their scores, two participants decreased their scores, and the remaining four participants scored the same during both sessions. The mean difference between the two sessions was an increase of 0.13, and the mean percentage increase was 1.85%.

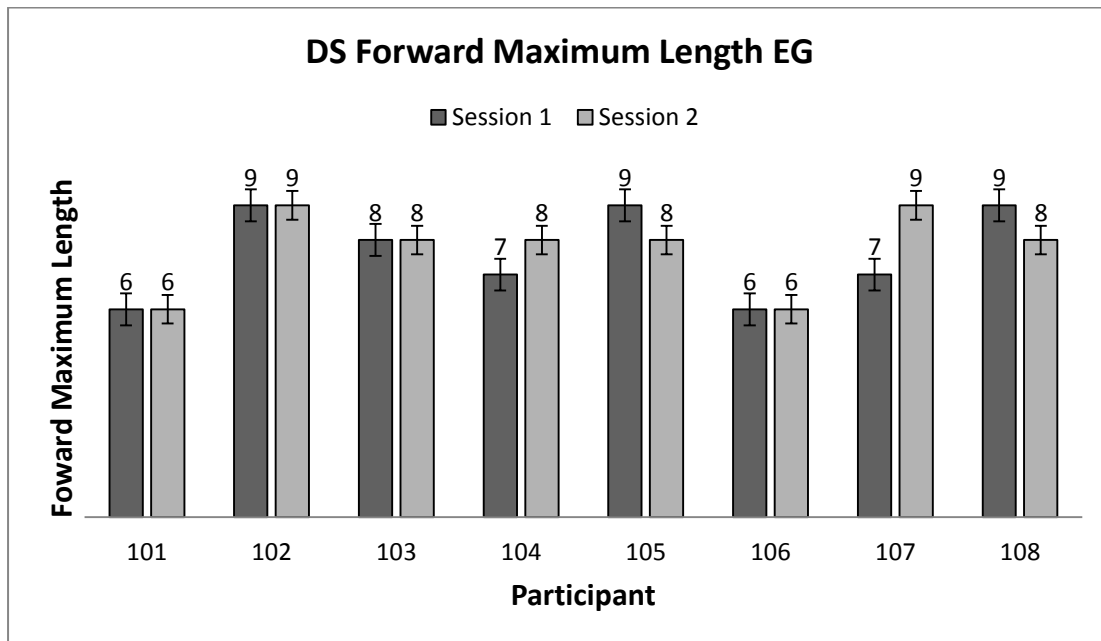


Figure 28. The digit span (DS) forward maximum length for all individual participants ($n = 8$) in the experimental group (EG), prior to hearing aid fitting (dark grey = Session 1) and after hearing aid fitting (lighter grey = Session 2). The numbers represent the individual score for that session, while the error bars display the standard error for each participant.

Digit span forward maximum length results from the normal hearing participants and those control group participants tested at S1 and retested at S2 (i.e. CG (S1-S2)), were analysed to account for any potential procedural learning effect. To examine any potential procedural learning effect, the mean score difference and the mean percentage difference were analysed. The normal hearing group demonstrated the greatest improvements, suggesting this change could be due to a learning effect. One-tailed Mann-Whitney U testing revealed no significant changes between sessions for any of the three groups assessed.

Table 15. Comparison of means at S1 and S2 (S1-S2) for the experimental group (EG), control group (CG) and normal hearing group (NH) on the digit span (DS) forward two-error maximum. The highlighted black rows indicate scores for which a potential learning effect could possibly be observed.

DS FORWARD MAXIMUM LENGTH	EG (n = 8)	CG (n = 16)	NH (n = 10)
Mean Forward Maximum Length Session 1	7.63	7.06	7.00
Mean Forward Maximum Length Session 2	7.75	6.81	7.40
Mean Forward Maximum Length (Session 1 + Session 2)/2	7.69	6.94	7.20
Mean Forward Maximum Length Standard Deviation	0.31	0.19	0.30
Mean Score Difference	0.13	-0.25	0.40
Mean Percentage Difference	1.85	-3.54	5.59
Mann-Whitney U value	31	124	37
Mann-Whitney U test p-value	0.469	0.447	0.174

4.4.1.3 Backward Two-Error Maximum

Three participants improved their scores, two participants decreased their scores, and the remaining three participants scored the same for both sessions. The mean difference between the two sessions was an increase of 0.13, and the mean percentage decrease was -2.02%.

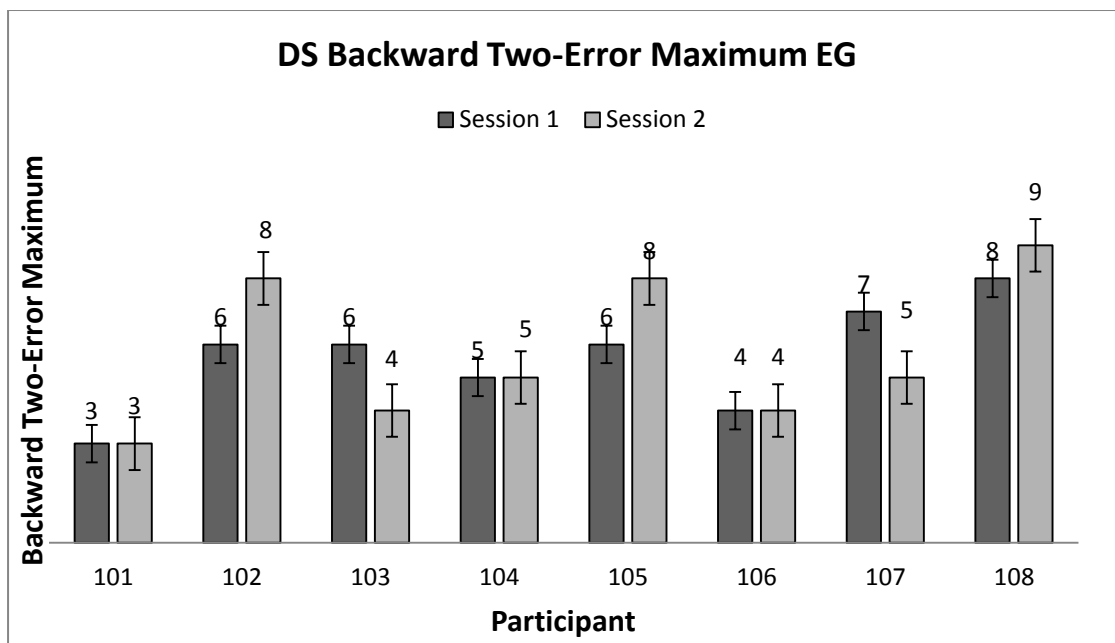


Figure 29. The digit span (DS) backward two-error maximum for all individual participants ($n = 8$) in the experimental group (EG), prior to hearing aid fitting (dark grey = Session 1) and after hearing aid fitting (lighter grey = Session 2). The numbers represent the individual score for that session, while the error bars display the standard error for each participant.

The experimental group on average performed the best for the digit span, backward two-error maximum. To examine any potential procedural learning effect, the mean score difference and the mean percentage difference were analysed. Considering this, improvements for the experimental group were the smallest, indicating no meaningful impact of hearing aid intervention for this dimension of the digit span assessments. One-tailed Mann-Whitney U testing revealed no significant changes between sessions for any of the three groups assessed.

Table 16. Comparison of means at S1 and S2 (S1-S2) for the experimental group (EG), control group (CG) and normal hearing group (NH) on the digit span (DS) backward two-error maximum. The highlighted black rows indicate scores for which a potential learning effect could possibly be observed.

DS BACKWARD TWO-ERROR MAXIMUM	EG (n = 8)	CG (n = 16)	NH (n = 10)
Mean Backward Two-Error Maximum Session 1	5.63	4.88	4.70
Mean Backward Two-Error Maximum Session 2	5.75	5.31	5.20
Mean Backward Two-Error Maximum (Session 1 + Session 2)/2	5.69	5.09	4.95
Mean Backward Two-Error Maximum Standard Deviation	0.56	0.41	0.75
Mean Score Difference	0.13	0.44	0.50
Mean Percentage Difference	-2.02	7.67	11.31
Mann-Whitney U value	31.5	109.5	40
Mann-Whitney U test p-value	0.492	0.246	0.229

4.4.1.4 Backward Maximum Length

Three experimental group participants improved their scores, one participant decreased their scores, and the remaining four participants scored the same for both sessions. The mean difference between the two sessions was an increase of 0.25, and the mean percentage increase was 2.54%.

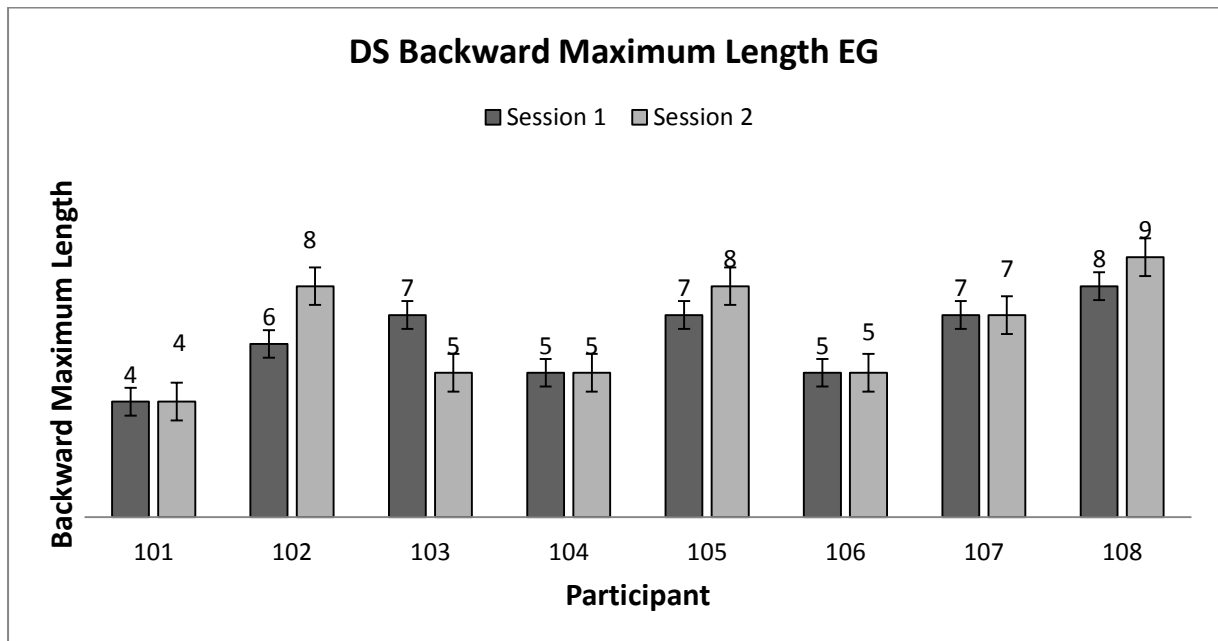


Figure 30. The digit span (DS) backward maximum length for all individual participants ($n = 8$) in the experimental group (EG), prior to hearing aid fitting (dark grey = Session 1) and after hearing aid fitting (lighter grey = Session 2). The numbers represent the individual score for that session, while the error bars display the standard error for each participant.

Digit span backward maximum length results from the normal hearing participants and those control group participants tested at S1 and retested at S2 (i.e. CG (S1-S2)), were analysed to account for any potential procedural learning effect. The experimental group on average performed the best. The control group and the experimental group both demonstrated improvements, suggesting a learning effect. One-tailed Mann-Whitney U testing revealed no significant changes between sessions for any of the three groups assessed.

Table 17. Comparison of means at S1 and S2 (S1-S2) for the experimental group (EG), control group (CG) and normal hearing group (NH) on the digit span (DS) backward maximum length. The highlighted black rows indicate scores for which a potential learning effect could possibly be observed.

DS BACKWARD MAXIMUM LENGTH	EG (n = 8)	CG (n = 16)	NH (n = 10)
Mean Backward Maximum Length Session 1	6.13	5.94	5.90
Mean Backward Maximum Length Session 2	6.38	6.19	5.90
Mean Backward Maximum Length (Session 1 + Session 2)/2	6.25	6.06	5.90
Mean Backward Maximum Length Standard Deviation	0.38	0.25	0.60
Mean Score Difference	0.25	0.25	0.00
Mean Percentage Difference	2.54	2.96	0.52
Mann-Whitney U value	29	114.5	49
Mann-Whitney U test p-value	0.393	0.305	0.496

4.4.2 Hearing Impaired versus Normal Hearing

Scores from the first session (S1) were compared to investigate any potential differences between those participants with hearing impairment: experimental group (n = 8) + control group (S1) (n = 27) for combined total of those demonstrating hearing loss (n = 35), contrasted against those with normal hearing thresholds (n = 10). The mean scores from the two groups are compared in Figure 31.

For both forward measures (the forward two-error maximum and the forward maximum length) the participants with hearing impairment performed better than those with normal hearing. However, the normal hearing group on average performed much better than the hearing impaired participants for backward two-error maximum score, and slightly better for the backward two-error maximum. This may be due to the fact that forward digit span relies on short term memory, while backward digit span indexes working memory. This is discussed more fully in Section 5.1.2 of the Discussion. Table 18 presents the mean, median and range for these scores.

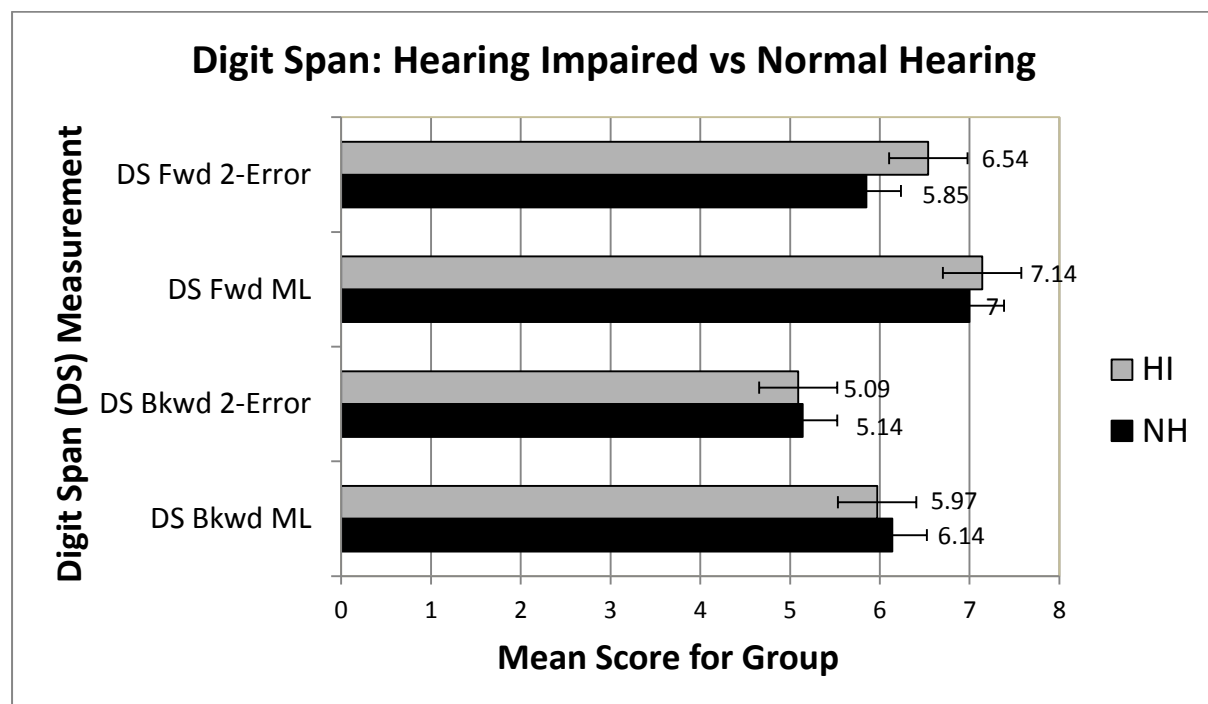


Figure 31. Comparison of first session scores from digit span (DS) for all participants with hearing impairment (HI) versus the normal hearing group (NH). The solid black box represents the hearing impaired participants (n = 35) while the light grey box represents the normal hearing group (n = 10). Scores listed are the digit span forward two-error maximum (DS Fwd 2-Error); the digit span forward maximum length (DS Fwd ML); the digit span backward two-error maximum (DS Bkwd 2-Error); and the digit span maximum length (DS Bkwd ML). The numbers represent the mean group score for that session, while the error bars display the standard error for each group.

Table 18. Comparison of first session scores from digit span (DS) for all participants with hearing impairment (HI) (n = 35) versus the normal hearing group (NH) (n = 10). Data includes mean, standard deviation of mean (SD), median and range. Scores listed are the digit span forward two-error maximum (DS Fwd 2-Error); the digit span forward maximum length (DS Fwd ML); the digit span backward two-error maximum (DS Bkwd 2-Error); and the digit span maximum length (DS Bkwd ML).

	<i>DS Fwd 2-Error</i>		<i>DS Fwd ML</i>		<i>DS Bkwd 2-Error</i>		<i>DS Bkwd ML</i>	
Group	HI	NH	HI	NH	HI	NH	HI	NH
Mean	6.54	5.86	7.14	7	5.09	5.14	5.97	6.14
SD	1.15	1.12	1.2	0.76	1.38	1.64	1.36	1.25
Median	6	6	7	7	5	5	6	6
Minimum	4	4	5	6	3	2	4	4
Maximum	9	7	10	8	8	8	8	8

4.4.3 Relationship between Hearing Loss Severity and Cognition

As described in Sections 2.3.3.2, hearing loss severity is anticipated to increase with age. As per Section 2.1.3, cognitive abilities were anticipated to decline with age. The following section investigates findings potentially associated with these relationships as they pertain to digit span (DS).

4.4.3.1 Correlations

Table 19 shows the results of one-tailed Spearman correlations for the variables of age, digit span forward two-error maximum (DS Fwd 2 Error), digit span forward maximum length (DS Fwd ML), digit span backward two-error maximum (DS Bkwd 2 Error), digit span backward maximum length (DS Bkwd ML), right ear four frequency pure-tone average (RE4PTA), and left ear four frequency pure-tone average (LE4PTA). Based on prevailing research literature, (Lin et al., 2013) it was projected that that hearing loss would be correlated with deficits in working memory, as measured by the digit span task. There were no significant correlations measured between either the RE4PTA or the LE4PTA and any measure of digit span as measured by Spearman's rho. As expected, all measures of digit span were significantly correlated with each other.

Table 19. Correlation matrix between digit span (DS) measures and hearing loss. The scores are digit span forward two-error maximum (DS Fwd 2 Error), digit span forward maximum length (DS Fwd ML), digit span backward two-error maximum (DS Bkwd 2 Error), digit span backward maximum length (DS Bkwd ML); left ear four frequency pure-tone average (LE4PTA); right ear four frequency pure-tone average (RE4PTA); and age.

	1	2	3	4	5	6	7
1 Age	1.00	.300*	.460**	.016	-.027	-.149	-.099
2 LE4PTA		1.00	.858**	.131	.080	.245	.218
3 RE4PTA			1.00	.107	.037	.120	.141
4 DS Fwd 2 Error				1.00	.692**	.476**	.445**
5 DS Fwd ML					1.00	.666**	.581**
6 DS Bkwd 2 Error						1.00	.822**
7DS Bkwd ML							1.00

*. Correlation was significant at the 0.05 level (1-tailed).

**. Correlation was significant at the 0.01 level (1-tailed).

4.4.4 Further Testing with Matched Participants

As explained in Section 4.3.4, participants in the experimental group were matched using hearing loss data to participants in the control group (S1-S2). This created two equally-sized groups, which were used for the following analyses.

4.4.4.1 ANOVA

A mixed-design analysis of variance was conducted to look for differences between the experimental group and the control group, and also for differences between Session 1 and Session 2 for the digit span (DS) measures: DS Forward Two-Error Maximum, DS Forward Maximum Length, DS Backward Two-Error Maximum, and Backward Maximum Length. For all measures there was homogeneity of variances, as assessed by Levene's test of homogeneity of variance ($p > .05$). All scores were normally distributed for both groups at both sessions, as assessed by examination of the residual (± 3 standard deviations). There was homogeneity of covariances, as assessed by Box's test of quality of covariance matrices. There

There was no statistically significant interaction between the intervention method of hearing aid use and sessions on any measures of digit span.

DS Forward Two-Error Maximum: $F(1,10) = 3.462, p = .092$, partial $\eta^2 = .257$

DS Forward Maximum Length: $F(1,10) = 2.000, p = .188$, partial $\eta^2 = .167$

DS Backward Two-Error Maximum: $F(1,10) = .044, p = .838$, partial $\eta^2 = .004$

DS Backward Maximum Length : $F(1,10) = .059, p = .813$, partial $\eta^2 = .006$

The effect of the hearing aids showed that there was no statistically significant difference in any measure of digit span between the experimental and control groups.

DS Forward Two-Error Maximum: $F(1,10) = .294, p = .599$, partial $\eta^2 = .029$

DS Forward Maximum Length: $F(1,10) = 1.623, p = .231$, partial $\eta^2 = .140$

DS Backward Two-Error Maximum: $F(1,10) = .727, p = .414$, partial $\eta^2 = .068$

DS Backward Maximum Length : $F(1,10) = .009, p = .926$, partial $\eta^2 = .001$

Post-hoc power analysis revealed the study was underpowered in some instances when considering potential interaction(s) between participant groups and sessions generating measures of digit span, as per the mixed model ANOVA. Power appeared sufficient for Forward Two-Error Maximum, calculated as 0.955 (95.5%). Power did was not adequate for: Forward Maximum Length = 0.798 (79.8%), Backward Two-Error Maximum = 0.068 (6.8%), and Backward Maximum Length = 0.078 (7.8%).

4.4.4.2 Partial Correlations

Matched data as explained in Section 4.3.4 was subjected to a partial correlation in order to explore the relationship between hearing loss and digit span measures while controlling for the effects of age. There were no significant correlations found.

RE4PTA	DS Forward Two-Error Maximum	$r(9) = .016, p = .481$
	DS Forward Maximum Length	$r(9) = .355, p = .142$
	DS Backward Two-Error Maximum	$r(9) = .002, p = .497$
	DS Backward Maximum Length	$r(9) = .095, p = .390$
LE4PTA	DS Forward Two-Error Maximum	$r(9) = .022, p = .474$
	DS Forward Maximum Length	$r(9) = -.124, p = .358$
	DS Backward Two-Error Maximum	$r(9) = -.519, p = .051$
	DS Backward Maximum Length	$r(9) = -.423, p = .097$

4.5 Summary of Important Findings

There were no statistically significant improvements in any measure of the auditory selective attention task or the digit span task. However, the experimental group did improve more than both the control and normal hearing groups for the auditory selective attention mean overall reaction time and reaction time digit tasks. This could possibly reach statistical significance, if there were greater participant numbers in the experimental group to account for outliers and enable normal distribution assumption, and if all groups were equal size.

There were significant relationships observed between overall percent correct and both four frequency pure-tone average for both the left and right ear (see Section 4.3.3.2). Further, overall mean reaction time was significantly correlated with both the right and the left ear four frequency pure-tone averages (see Section 4.3.3.3). Mean reaction time digit was almost significantly correlated with hearing loss (see Section 4.3.3.4), which perhaps would have reached significance with a larger sample size. To control for the variable of age, a partial correlation was conducted which revealed auditory selective attention overall percent correct and left ear four frequency pure-tone average were still significantly correlated. These results suggest a relationship between the severity of hearing loss and the measure employed by this study to index auditory selective attention.

There were no significant results found between hearing loss and working memory as measured by the digit span task.

5 Discussion

This study was designed to assess the relationship between hearing loss and cognition, and additionally the role of hearing aids in preventing cognitive decline. The aims of study were:

1. Determine if individuals with hearing loss are at risk for selective attention and working memory cognitive deficits.
2. Determine if hearing aid fitting was sufficient to improve or arrest aspects of hearing loss-related cognitive decline, particularly selective attention and working memory.

The first aim pertained to hearing loss and cognition. Hearing loss has been shown to be associated with cognitive decline (Lin et al., 2013; Lin, 2011). This study aimed to see if working memory and auditory selective attention abilities were reduced in older participants with hearing loss compared to their normal hearing peers. We hypothesized that our participants who have hearing loss would perform worse when administered cognitive tasks, than older people with normal hearing. We also wanted to examine the relationship between hearing loss severity and cognition.

The second aim pertained to hearing aids and cognition. There have been studies showing varying results in the role of hearing aids and different aspects of cognition (Acar et al., 2010; Choi et al., 2011; Dawes et al., 2015; Mulrow et al., 1990). However, the general consensus has been that hearing aids have a positive effect on cognition, although the long-term effects are unknown (Kalluri & Humes, 2012). From this, we hypothesized that use of hearing aids over approximately 3 weeks would result in significant improvements in auditory selective attention, as assessed by the auditory selective attention task (ASA), and working memory, as assessed by digit span (DS).

The findings of this study could be clinically relevant. If hearing aids could be utilised as a means of slowing or reversing an aspect of cognitive decline, it would suggest another reason/rationale for people to consider acquiring hearing aids potentially sooner, in addition to the social and emotional benefits indicated by research (Ciorba et al., 2012; Dalton et al., 2003). Further research could be undertaken in cognition and hearing aid use, to determine what other cognitive benefits hearing aids could conceivably provide. Clinically, this could have large implications in

hearing aid uptake considering on-going benefits that hearing aids may be shown to provide. Further, this intervention method could be an application of the emerging concept of ‘Pervasive Healthcare’ – a model based on providing healthy lifestyles to the entire population through use of pervasive prevention, monitoring and technology (Varshney, 2005). Interventions such as those featured in this study give the user the control, and allow the user to improve their own health using their own initiative, thus achieving user-centred preventative healthcare (Arnrich, Mayora, Bardram, & Tröster, 2010).

5.1 Findings

5.1.1 Auditory Selective Attention Task

As explained in Section 2.3.4.1, auditory selective attention is the ability to focus on something which the brain needs to focus on, in the presence of perceptual ‘objects’ which are competing for attention. Auditory scene analysis is the theory that the brain groups similar perceptual inputs into separate ‘auditory streams’, and thus is able to focus on the target stream while the brain filters out the unwanted ‘noise’ or perceptually unimportant events (Bregman, 1990, p. 10; Cherry, 1953). Auditory scene analysis abilities are decreased in people with hearing loss (Bayat et al., 2013). A study found that adults with mild-to-moderate sensorineural hearing loss did significantly worse compared to people with normal hearing in an auditory scene analysis ability test (Bayat et al., 2013). Additionally, older people with hearing loss have decreased auditory selective attention abilities, due to cognitive decline (Barr & Giambra, 1990; Commodari & Guarnera, 2008; Panek & Rush, 1981).

The present study used the auditory selective attention task to measure overall percent correct, mean overall reaction time and mean reaction time digit. The findings which arose from this task will be discussed.

5.1.1.1 *Aided versus Unaided*

This study found that the participants in the experimental group showed decreased overall reaction time and decreased mean reaction time digit for the auditory selective attention task. It was not statistically significant for either measure, as seen in Table 10 and 11; however the experimental group obviously improved more than both the control group and the normal hearing group, with the normal hearing group actually performing slower on average for the reaction time digit.

This finding supports the research that there may be a relationship between hearing aid use and improved cognition (Lin, 2011). The participants in the experimental group showed clear improvements in reaction times. Cognitive skills have been shown to improve with hearing aid use, although to what extent remains unknown (Kalluri & Humes, 2012).

Fabiani and Gratton (2013) found older participants have less selective attentional control than younger participants; resulting in diminished ability to ignore distractor-stimuli. Similarly, Commodari and Guarnera (2008) found an age-related reduction in some aspects of attention, which is significantly greater in 60-65 year olds compared to 55-59 year olds. This research suggests that one should expect auditory selective attention abilities to decline with age. It is thought that age-related deficits in attention are possibly related to an inability to ignore or filter out irrelevant distractors to focus on the target (Barr & Giambra, 1990).

Attention has been shown to improve in populations with attention deficits following some sort of treatment, for example, attention process training (Sohlberg et al., 2000). The use of hearing aids as a means of treatment for hearing loss related attention deficits remains a somewhat novel idea, requiring further research. However hearing aid uptake can be low (Knusden et al., 2010). This is often due to the attitude towards hearing aids and hearing loss. A study by Humes, Wilson, and Humes (2003) compared participants who chose to trial hearing aids and those who did not, when matched for age, gender, and hearing thresholds. Those who chose not to trial hearing aids differed from their peers in the fact that they had less overall denial of their communication problems and were less likely to think they required hearing aids (Humes et al., 2003). Improvements in attentional abilities may argue for additional hearing aid benefits apart from previously established cognitive

improvements; which could potentially encourage positive attitudes towards hearing impairment, thus resulting in increased amplification trial and/or uptake.

For this study, there was no similar finding regarding hearing aid use and ASA Overall Percent Correct. This may be due to the limitations of the task. Many participants scored very highly in the first session, with the mean first session score for the experimental group being 71.09, as shown in Table 9. The two participants who demonstrated the greatest increase in raw score, were also the two participants who obtained the lowest, and second-lowest raw score, for Session 1. A more difficult task could influence these results, as there may be more improvements to be made. It may be that the ease of the ASA task facilitated a ‘ceiling effect’, thereby making marked improvement difficult to distinguish with the second administration of the task.

5.1.1.2 *Normal Hearing versus Hearing Impaired*

Group scores for Session 1 for all people with hearing impairment (i.e., the experimental group (n = 8) and control group (S1) (n = 27)) and those in the normal hearing group were compared. No clear trends were seen across these groups for the present study.

Other literature shows a link between those with hearing loss and more pronounced cognitive decline, as compared to those without hearing loss (Lin, 2011). However, this research, when comparing the same categories, did not reveal similar findings. A potential problem could have been sample size, as the number of participants with hearing impairment for this study was 35, while the number of participants in the normal hearing group was 10. Potentially, if the groups were better matched in sample size, and additionally better matched in demographic data (i.e. age, sex, education etc.) more uniform comparison would have been facilitated, and the results more in line with the recent research.

5.1.1.3 *Hearing Loss Severity*

The expected relationship between cognitive decline and hearing loss was evident when comparing for severity of hearing loss. Left ear four frequency pure-tone average (LE4PTA) was significantly correlated with two of the three measures of the ASA task – overall percent correct ($p <$

0.01) and overall reaction time ($p < 0.05$) (see Table 12). Specifically, a higher LE4PTA was significantly correlated with lower scores on the ASA task. Additionally the right ear four frequency pure-tone average (RE4PTA) was significantly correlated with overall percent correct ($p < 0.01$) and overall reaction time ($p < 0.01$) (see Table 12). Again, a greater RE4PTA indicating more severe hearing loss produced worse scores on the ASA task. Similarly, mean reaction time digit measures were close to significance. Even when controlling for age, LE4PTA was still significantly correlated with overall percent correct ($p < 0.05$) (see Section 4.3.4.5). With greater participant numbers, it could potentially be expected that more variables would reach significance in this partial correlation. This could be seen as a meaningful, powerful underlying trend in the data, emerging despite low participant numbers.

This is similar to the study conducted by Lin (2011), which found more severe forms of - hearing loss were significantly associated with lower scores on cognitive tests. This study consisted of a much larger sample size ($n = 605$) and scores were significantly lower, even after adjustment for demographic information and medical history. The study found that a 25 dB HL hearing loss was equivalent to an age difference of 7 years (Lin, 2011). Other research has found similar results (Quaranta et al., 2014; Uhlmann et al., 1989; Valentijn et al., 2005) (see Section 2.5.2).

Even with our much smaller sample size, we still found a significant relationship between four frequency pure-tone average and cognition, as measured by the ASA task. The participants involved in the current research consisted of those who had varying degrees of presbycusis, a condition which tends to progress over time, causing further deterioration evident in individual's hearing test results (Gacek & Schuknecht, 1969; Schuknecht, 1964). The findings of this research suggest that as hearing loss increases, cognitive abilities show a corresponding decrease. Following on from this, it is possible that improved hearing may conceivably prevent or slow cognitive decline. Currently the leading clinical management for those presenting with presbycusis of an aidable degree, involves the prescription of amplification (Dillon, 2012). This would suggest a need to increase our knowledge surrounding the benefits of hearing aid use on cognitive aging.

5.1.2 Digit Span

The results for the digit span task (DS) were unexpected. There were no significant trends relating hearing loss to working memory. No significant outcomes for this study did appear to support recent research which points to working memory as being important to hearing loss, due to the theory of cognitive load (Sweller et al., 2011). The concept is that the brain of a hearing impaired person requires additional effort to listen, and subsequently to understand (Martini et al., 2014). This leaves less cognitive capacity for other tasks, such as those that measure working memory (Tun et al., 2009).

The results of the present study showed that when compared to the normal hearing counterparts, the experimental group participants demonstrated the ability to remember longer digit strings correctly when recalling in the forward condition, before the two-error cut off was reached. The experimental group similarly exhibited a greater maximum length of digits correctly retained for the forward condition as well. The digit span forward condition is associated with short-term memory ability. However, when compared to the experimental group participants, those with normal hearing revealed somewhat better skill for remembering longer digit sequences accurately when recalling in the backward condition. The normal hearing participants also showed a slightly greater maximum length of digits correctly retained for the backward condition. The digit span backward condition indexes working memory (see Section 4.4.2; Figure 31). It may be that those with hearing loss and consequently, the potential for reduced ability in handling cognitive load, rely more on short-term memory as a coping strategy. This may also help explain the greater forward two-error maximum scores achieved for the control group and the experimental group as compared to normal hearing counterparts (see Table 14). Whereas, those with normal hearing and presumably normal cognitive facility, can maintain an edge over their hearing loss counterparts in working memory proficiency. However, these differences did not reach statistical significance for the present study.

A possible cause is that the task used to measure working memory may have not been sensitive enough due to the scoring system used, and research has suggested alternative scoring methods (Conway et al., 2005). Compared to the auditory selective attention task, which had a huge range of possible results due to the reaction time being measured in milliseconds, and the score being

measured in percentage, the digit span task had a much smaller range for results. The result for an individual participant was a discrete value, which was always between 2 and 10. A more sensitive working memory measure could be employed on future studies, for example, a computerised complex span task which is currently in development (Oswald, McAbee, Redick, & Hambrick, 2015).

5.2 Alternative Explanations for Findings

As there is insufficient evidence to explain the mechanisms to precisely account for why hearing loss appears to contribute to accelerated cognitive aging, other possibilities for the findings of the present study should be explored.

5.2.1 Self-efficacy

Self-efficacy is having belief in oneself that they possess the required skills to complete a specific task (S. L. Smith & West, 2006). It differs from self-confidence in the fact it is domain-specific, so applies to a certain activity rather than general confidence (S. L. Smith & West, 2006). Self-efficacy has been shown to be associated with improved hearing aid fitting success rates (Hickson, Meyer, Lovelock, Lampert, & Khan, 2014). This relates to cognitive outcomes as associated with reduced self-efficacy, with poorer self-efficacy shown to influence performance on challenging tasks (Bouffard-Bouchard, 1990).

In the present study, participants in the experimental group completed two subjective measures, the Hearing Handicap Inventory for Adults (Newman et al., 1991) and the Abbreviated Profile of Hearing Aid Benefit (R. M. Cox & Alexander, 1995). The APHAB measures the level of benefit experienced by new hearing aid users in specific listening situations; while the HHIA measures the level of hearing handicap experienced by the person with hearing loss prior to and after hearing aid fitting. Therefore neither is a direct measure of self-efficacy. However, both do provide some insight into the subjective impressions related to hearing aid use and hearing handicap, as experienced by a new hearing aid user.

According to the guidelines of Newman et al. (1991) which suggests that a change of 12 points is required to be clinically meaningful, 6 of the 8 experimental group participants experienced

this recommended level of change for the HHIA (see Table 8). Although the APHAB does not presently have a similar guide informing clinically meaningful change, group comparison of prior to and after hearing aid fitting showed significant changes ($p < 0.01$) for Ease of Communication, Background Noise and the Global score (see Table 7). Such subjective improvements suggest that these participants may have been feeling more confident in their hearing ability, due to the use of hearing aids. Broadly speaking, this may potentially influence self-efficacy.

The attention and memory tasks were administered via headphones and experimental group participants did not wear their hearing devices during task engagement. However, if experimental group participants experienced increased self-efficacy through their trial of hearing aids, perhaps that was generalised to other contexts and potentially influenced their performance on the cognitive tasks. This is a possibility suggested by another study (Dawes et al., 2015). The Dawes et al. (2015) study found hearing aid use is associated with better cognition, but suggested that these improvements could be related to improved self-efficacy, which affected (i.e. enhanced) cognitive tasks results. This finding lead to a call for further research into the mechanisms behind other possible links between hearing loss and cognition (Dawes et al., 2015).

In future research a measure of self-efficacy could be used. The Measure of Audiologic Rehabilitation Self-Efficacy for Hearing Aids (MARS-HA) is a self-efficacy questionnaire which has recently been developed to aid audiologists (West & Smith, 2007). The audiologist is able to identify areas where the client experiences low self-efficacy, in order to focus their instruction on specific situations, thereby boosting the client's self-efficacy and ideally leading to a more successful hearing aid fitting (West & Smith, 2007). Further studies into hearing aid use and cognition should consider using this tool, to better explain the reasons behind the observed cognitive improvements.

5.3 Critique of Current Study

This section aims to identify any issues with the current study, and suggest alternative options which should be utilised in future research in order to ameliorate these problems.

5.3.1 Participants

As previously mentioned, there is a clear limitation in the fact that the group sizes were uneven, especially regarding the small sample size in the experimental group. The a priori consideration analysis required 20 participants in each group, which this study did not achieve. A larger experimental group could have allowed better statistical comparisons between the control and experimental groups and possibly aided in ensuring the study was sufficiently powered. As demonstrated by post-hoc power analyses, the study was underpowered for the majority of ANOVA calculations, indicating that the likelihood of the study returning a statistically significant result was reduced, and that which did reach statistical significance should be interpreted with caution. Regardless, there were clear trends emerging regarding the auditory selective attention task and hearing loss severity. Ensuring sufficient power in future studies examining the relationship between hearing loss and cognition will allow researchers to have more confidence in their results.

The composition of the groups was different as well. The normal hearing group was comprised of a younger population. This was due to the difficulty in finding age-matched people who had hearing levels less than 20dB HL between all frequencies of 250 and 8000 Hz. Furthermore, the majority of participants in both the control and normal hearing groups were females, while the experimental group were equally men and women. This limits the ability of the control group to serve as a true control, and thus reduces the strength of the statistical analysis. However attempts were made to counteract this through post-hoc group matching and the statistical analyses considered e.g. Sections 4.3.4 and 4.4.4.

The participants also came from different backgrounds. While the vast majority of the control group had participated in research before, as they were recruited through a previous study, *Understanding how listeners comprehend distorted speech* (McAuliffe & Sinex, in progress), the

majority ($n = 6$) of the experimental group were not previous research participants, and may therefore have experienced additional anxiety about the cognitive tests and the research environment in general. The participants in the experimental group were embarking on a personal and potentially life-changing experience by undergoing a hearing aid trial, and the additional involvement in research of a cognitive testing nature may have deterred potential participants from volunteering, resulting in reduced experimental group participants.

If there was more time available it would be useful to age and gender match participants, and form larger groups of equal size, producing a stronger study.

5.3.2 Software

There were some problems with the software that may have influenced results. The software required the use of a mouse, to enable participants to select their answer. Although participants were instructed of the use of the computer prior to volunteering for the project, it was clear that some participants were more familiar with computers than others. This was particularly evident in some participant's abilities with the mouse – while some required more effort to control it, others were obviously well-practiced. As ASA reaction time is a measure of the time it takes the participant to move the mouse to the correct answer, this could potentially affect the results. This may have been why the correlation between hearing loss and reaction time digit was close to, but did not reach, significance (see Section 4.3.3.4). However, for the analysis of results in an individual participant, i.e. for the same participant prior to and post hearing aid fitting, this should not be an issue, due to the fact that the participant is being compared against themselves, and not others. Despite this, the experimental group showed a decrease in reaction time following amplification trial, which was a similar finding revealed in larger studies (Kalluri & Humes, 2012; Mulrow et al., 1990).

A similar software-based issued was noted for the measurement of ASA overall reaction time. The overall reaction time measures from the appearance of the response screen to the selection of the colour. The software developers note that the mouse is in the position the participant left it, so while some participants may have moved it away from the box they wanted to ultimately click to register their response, others may have left the mouse nearby. A solution for this would be to adjust the

software so the mouse is always in the same start position. Alternatively, a better solution would be to use a touch screen. This would eliminate any of the mouse control problems mentioned earlier. Participants could be instructed to leave their hands on the table until the response screen appears, to gain a more accurate reaction time.

An on-going problem with the software which should be addressed for future studies is in relation to the digit span (DS). When the DS presents the participant with a string of digits, the maximum number of characters that the participant can enter is equal to the number of presented digits. Thus if the computer presents “two, nine, eight, six”, the maximum number of digits the participant can enter is four. Although the participant is essentially wrong if they want to enter more than the presented number of digits, it can be off-putting for those inclined to halt the task to query why they were not able to enter their entire answer. This may affect results as the initial occurrence may contribute to participant distraction and potentially delay the task from running smoothly. There should be no maximum number of digits able to be entered into the response box.

5.3.3 Method

Regarding the methodology, there was an experimental group consisting of new hearing aid users and a control group to compare them against. Following the completion of some of the data collection, consideration of likely outcomes suggested it was important to determine if any improvements were due to the hearing aids, or actually just the result of a learning effect. Thus the control group were invited back to be retested, and additionally the formation of a normal hearing group began.

The experimental group waited approximately 3 weeks between sessions. In comparison, the control group (S1-S2) had on average 72 days between sessions. This is a much longer time period, and likely affected task recall for the control group at session 2 (S2). The formation of the normal hearing group slightly ameliorated this problem, as the normal hearing group all had a very short, conservative time between sessions (mean = 12 days) to exploit any potential learning effect. However, the different amount of time between sessions for the control group and experimental group made straightforward comparisons more difficult. Another consideration which should be made

concerns the timing of the cognitive tasks for the experimental group. Unlike the control group, whose only task of the day was to complete the cognitive testing, the experimental group were also seeing the audiologist. On the day of the fitting they are shown their new hearing aids, instructed how to use them, and undergo an appointment of around an hour. Ideally, participants would have been tested prior to their appointments to reduce fatigue but this was not always possible. Participants may have been experiencing some anxiety about the hearing aids, or additional cognitive stress due to the demands of learning a new piece of technology. As these were cognitive tasks they were performing, this could have affected results. In the future, the ideal solution would be to test all participants prior to their appointment, to avoid this situation.

A final point which should be made is the fact that three weeks may not be a long enough time period to properly observe all cognitive changes. The reason three weeks was chosen as the retesting timing for the experimental group was: 1) due to the timing of typical, clinical hearing aid follow-up schedules in New Zealand and 2) due to findings associated with a previous study which saw significant reductions in hearing loss-related, subjective tinnitus complaint, following nearly three weeks of selective attention training (Wise, Kobayashi, & Searchfield, 2015). Future study would ideally test participants multiple times following the hearing aid fitting, not over simply weeks but maybe months or years. This could help track the progress of the participants and provide an indication of cognitive areas where hearing aids are helpful in the short-term, compared to the long-term effects, and also whether any effects are lasting or diminish with the passage of time.

5.4 Future Considerations

The aim of this section is to suggest areas of study future research could focus on, given the results and the limitations of the current study. Additionally, considerations about future projects will be discussed.

5.4.1 Hearing Aids and Cognition

A large proportion of people with hearing loss could benefit from hearing aids, however research shows that a large proportion of these people do not have hearing aids, or do not use them if they do have them (Smits, Kramer, & Houtgast, 2006). Hearing loss has been linked to social isolation (Mick et al., 2014), decreased quality of life (Dalton et al., 2003), conflict between spouses when one partner has hearing loss (Héту et al., 1988), and cognitive decline (Lin, 2011; Lin et al., 2013). The effects of hearing loss can be severe (Perissinotto et al., 2012), and hence there is a strong need for encouraging the use of management strategies and treatments to prevent or reduce these consequences (Ciorba et al., 2012). Hearing aids are a means to achieve this goal. This study aimed to look at the interaction between hearing aids and cognition.

The effect of hearing aids on cognition is relatively new research territory (Kalluri & Humes, 2012). The present study found that hearing aids were shown to have a positive effect on certain aspects of cognition, which could potentially act as a facilitator to encourage hearing aid uptake. Specifically, decreased reaction time for those in the experimental group who acquired hearing aids as opposed to those in the control group or normal hearing group, although it was not statistically significant (see Table 10). This improvement in cognition was similar to findings shown in previous research (Kalluri & Humes, 2012; Mulrow et al., 1990). Further research is required to better understand the relationship between hearing loss and cognition. As modern medicine continues to allow people to live longer, it is apparent that there needs to be support in place to ensure high standards of quality of life for the growing aging population (Butler et al., 2004).

Future research into hearing aids and cognition should focus on longitudinal studies determining the effect of hearing aids on cognition. As mentioned in Section 5.3.3, one of the

limitations of this study was the short time period in which the entire study had to be conducted. This meant there was not an opportunity to test participants any further, and see whether any changes were lasting or changing with time. An upcoming study run by Johns Hopkins University and the University of South Florida is a longitudinal randomised controlled trial of around 1000 healthy, cognitively normal community dwelling adults with untreated mild to moderate hearing loss (Mamo & Lin, 2015). Those who obtain hearing aids will be compared to those who do not obtain hearing aids. Regular assessments over multiple years will measure hearing, cognitive function, and secondary outcomes such as hearing-related quality of life. This study will hopefully provide new insights into cognitive aging and hearing aid use.

5.4.2 Hearing Aid Technology

During data analysis, this study considered the idea that higher levels of technology could result in greater cognitive improvements. This could be a motivating factor for clients to use more advanced hearing aids, and also generate additional need for more complex technology. This has been considered in other studies (Bertoli, Bodmer, & Probst, 2010; R. M. Cox, Johnson, & Xu, 2014). R. M. Cox et al. (2014) compared lower-cost basic level hearing aids with higher-cost premium level hearing aids by measuring speech understanding for new and experienced hearing aid users. That research found no difference in improvements in speech understanding with the two levels of technology. A different study discusses the relationship between the level of hearing aid signal processing and successful hearing aid fittings, and found that more advanced signal processing may contribute to a more successful fitting, although the improvements may be minor (Bertoli et al., 2010).

For the present study, there were no significant findings regarding the relationship between the level of technology of the hearing aid, and any improvements on the cognitive tasks. However, due to the same sample size for the experimental group ($n = 8$), it is unclear whether a larger sample size would have yielded a different outcome. Additionally, the hearing aids of the experimental group were divided into four different technology levels, which resulted in minimal numbers in each group (i.e. Elite Technology Level, $n = 3$; Advanced, $n = 3$; Active, $n = 1$; Essential, $n = 1$). Further research could consider the differences in hearing aid technology, and if any additional central benefits are

acquired through the use of more advance devices. Interestingly, the two studies that investigated the impact of hearing aids on cognition which showed no improvements on cognition with aiding (Allen et al., 2003; van Hooren et al., 2005) used devices that are now over a decade old. It may be that if these studies were repeated with present-day devices, featuring comparatively more advanced technology than what was available at the time those studies were conducted, outcomes might differ.

5.4.3 Type of Hearing Loss

The hearing loss characteristics of all participants were described in Section 4.1.4. There has been some thought that there is a relationship between a high-low hearing loss and poor performance on certain auditory processing disorder (APD) tests (L. C. Cox, McCoy, Tun, & Wingfield, 2008). The study conducted by L. C. Cox et al. (2008) defined a high-low hearing loss as one in which measured hearing loss was present in both the low and high frequencies, which is different from the typical, slightly sloping high-frequency hearing loss seen in many cases of presbycusis (see Section 2.3.3.2). This research was applied to this study, to consider the possibility that participants with a high-low hearing loss experienced additional attention deficits, as evidenced by worse performance on the attention task.

Unfortunately the current study was again restricted by sample size. There were only 5 participants who met the criteria determined by L. C. Cox et al. (2008) to qualify as meeting the requirements for a high-low hearing loss, while their study measured 15 participants. Analysis of our data revealed that there were no clear trends when comparing their scores to the mean for other participants in our study of the same age group who had a high frequency hearing loss only. This is in contrast to the findings of L. C. Cox et al. (2008). This could be due to the small sample size of the current study, again suggesting a need for further investigation.

5.5 Conclusion

The aims of this study were to look at the relationship between hearing loss, hearing aids and cognition. Hearing loss severity was shown to be related to cognition (see Table 12) and the experimental group trialling amplification showed improved scores on measures of the auditory selective attention task. This agrees with other findings suggesting a relationship between cognitive decline and hearing loss (Lin, 2011), and hearing aids as a means to reduce loss-related cognitive deficits (Dalton et al., 2003; Mulrow et al., 1990). Although further research appears warranted, this project adds to the increasing body of literature on hearing loss and cognition. The outcome of these studies could potentially lead to increased uptake of hearing aids, encouraging use at an earlier stage following clinical diagnosis of hearing loss. Although amplification has historically targeted hearing loss, application of this technology could possibly slow cognitive aging, prevent social isolation, reduce communication difficulties associated with emotional hardships, and improve the quality of life for the growing population of older adults with hearing impairment.

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Appendix A: Hearing Handicap Inventory for Adults

Hearing Handicap Inventory for Adults (HHIA)

Participant: [Type name here](#)

Date: [Click here to enter a date.](#)

*Please check "yes," "no," or "sometimes" in response to each of the following items.
Please do not skip any questions. Please select only one answer per question.*

1. Does a hearing problem cause you to use the phone less often than you would like?
No ☐ Sometimes ☐ Yes ☐
2. Does a hearing problem cause you to feel embarrassed when you meet new people?
No ☐ Sometimes ☐ Yes ☐
3. Does a hearing problem cause you to avoid groups of people?
No ☐ Sometimes ☐ Yes ☐
4. Does a hearing problem make you irritable?
No ☐ Sometimes ☐ Yes ☐
5. Does a hearing problem cause you to feel frustrated when talking to members of your family?
No ☐ Sometimes ☐ Yes ☐
6. Does a hearing problem cause you difficulty when attending a party?
No ☐ Sometimes ☐ Yes ☐
7. Do you have difficulty hearing or understanding co-workers, clients, or customers?
No ☐ Sometimes ☐ Yes ☐
8. Do you feel handicapped by a hearing problem?
No ☐ Sometimes ☐ Yes ☐
9. Does a hearing problem cause you difficulty when visiting friend, relatives or neighbours?
No ☐ Sometimes ☐ Yes ☐
10. Does a hearing problem cause you to feel frustrated when talking to co-workers, clients, or customers?
No ☐ Sometimes ☐ Yes ☐
11. Does a hearing problem cause you difficulty in the movies or in the theatre?
No ☐ Sometimes ☐ Yes ☐

12. Does a hearing problem cause you to be nervous?
 No ☐ Sometimes ☐ Yes ☐
13. Does a hearing problem cause you to visit friends, relatives of neighbours less often than you would like?
 No ☐ Sometimes ☐ Yes ☐
14. Does a hearing problem cause you to have arguments with family members?
 No ☐ Sometimes ☐ Yes ☐
15. Does a hearing problem cause you difficulty when listening to the TV or radio?
 No ☐ Sometimes ☐ Yes ☐
16. Does a hearing problem cause you to go shopping less often than you would like?
 No ☐ Sometimes ☐ Yes ☐
17. Does any problem or difficulty with your hearing upset you at all?
 No ☐ Sometimes ☐ Yes ☐
18. Does a hearing problem cause you to want to be by yourself?
 No ☐ Sometimes ☐ Yes ☐
19. Does a hearing problem cause you to talk to family members less often than you would like?
 No ☐ Sometimes ☐ Yes ☐
20. Do you feel that any difficulty with your hearing limits or hampers your personal or social life?
 No ☐ Sometimes ☐ Yes ☐
21. Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?
 No ☐ Sometimes ☐ Yes ☐
22. Does a hearing problem cause you to feel depressed?
 No ☐ Sometimes ☐ Yes ☐
23. Does a hearing problem cause you to listen to TV or radio less often than you would like?
 No ☐ Sometimes ☐ Yes ☐
24. Does a hearing problem cause you to feel uncomfortable when talking to friends?
 No ☐ Sometimes ☐ Yes ☐
25. Does a hearing problem cause you to feel left out when you are with a group of people?
 No ☐ Sometimes ☐ Yes ☐

Appendix B: Abbreviated Profile of Hearing Aid Benefit

ABBREVIATED PROFILE OF HEARING AID BENEFIT

NAME: _____ DATE: _____ FILE NO.: _____

INSTRUCTIONS:

Please circle the answers that come closest to your everyday experience. Notice that each choice includes a percentage. You can use this to help you decide on your answer. For example, if the statement is true about 75% of the time, circle C for that item.

- A Always (99%)
- B Almost Always (87%)
- C Generally (75%)
- D Half-the-time (50%)
- E Occasionally (25%)
- F Seldom (12%)
- G Never (1%)

If you have not experienced the situation we described, try to think of a similar situation that you have been in and respond for that situation. If you have no idea, leave that item blank

Notice that for some items, an answer of Always (99%) means you have few problems. Other items are written so that an answer of Always (99%) means you have a lot of problems. Here is an example. In item (a), an answer of Always (99%) means that you usually have problems. In item (b), the same answer means that you only have problems once in a while.

EXAMPLE

		Without Hearing Aids	With Hearing Aids
(a)	When I'm talking with a friend outdoors on a windy day, <i>I miss a lot of the conversation.</i>	A B C D E F G	A B C D E F G
(b)	When I am in a meeting with several other people, <i>I can comprehend speech.</i>	A B C D E F G	A B C D E F G

Please begin answering the questions on the next page

A Always (99%)
B Almost Always (87%)
C Generally (75%)
D Half-the-time (50%)
E Occasionally (25%)
F Seldom (12%)
G Never (1%)

	Without Hearing Aids	With Hearing Aids
1. When I am in a crowded grocery store, talking with the cashier, I can follow the conversation.	A B C D E F G	A B C D E F G
2. I miss a lot of information when I'm listening to a lecture.	A B C D E F G	A B C D E F G
3. Unexpected sounds, like a smoke detector or alarm bell are uncomfortable.	A B C D E F G	A B C D E F G
4. I have difficulty hearing a conversation when I'm with one of my family at home.	A B C D E F G	A B C D E F G
5. I have trouble understanding the dialogue in a movie or at the theater.	A B C D E F G	A B C D E F G
6. When I am listening to the news on the car radio, and family members are talking, I have trouble hearing the news.	A B C D E F G	A B C D E F G
7. When I'm at the dinner table with several people, and am trying to have a conversation with one person, understanding speech is difficult.	A B C D E F G	A B C D E F G
8. Traffic noises are too loud.	A B C D E F G	A B C D E F G
9. When I am talking with someone across a large empty room, I understand the words.	A B C D E F G	A B C D E F G
10. When I am in a small office, interviewing or answering questions, I have difficulty following the conversation.	A B C D E F G	A B C D E F G

A Always (99%)
B Almost Always (87%)
C Generally (75%)
D Half-the-time (50%)
E Occasionally (25%)
F Seldom (12%)
G Never (1%)

	Without Hearing Aids	With Hearing Aids
11. When I am in a theater watching a movie or play, and the people around me are whispering and rustling paper wrappers, I can still make out the dialogue.	A B C D E F G	A B C D E F G
12. When I am having a quiet conversation with a friend, I have difficulty understanding.	A B C D E F G	A B C D E F G
13. The sounds of running water, such as a toilet or shower, are uncomfortably loud.	A B C D E F G	A B C D E F G
14. When a speaker is addressing a small group, and everyone is listening quietly, I have to strain to understand.	A B C D E F G	A B C D E F G
15. When I'm in a quiet conversation with my doctor in an examination room, it is hard to follow the conversation.	A B C D E F G	A B C D E F G
16. I can understand conversations even when several people are talking.	A B C D E F G	A B C D E F G
17. The sounds of construction work are uncomfortably loud.	A B C D E F G	A B C D E F G
18. It's hard for me to understand what is being said at lectures or church services.	A B C D E F G	A B C D E F G
19. I can communicate with others when we are in a crowd.	A B C D E F G	A B C D E F G

A Always (99%)
B Almost Always (87%)
C Generally (75%)
D Half-the-time (50%)
E Occasionally (25%)
F Seldom (12%)
G Never (1%)

	Without Hearing Aids	With Hearing Aids
20. The sound of a fire engine siren close by is so loud that I need to cover my ears.	A B C D E F G	A B C D E F G
21. I can follow the words of a sermon when listening to a religious service.	A B C D E F G	A B C D E F G
22. The sound of screeching tires is uncomfortably loud.	A B C D E F G	A B C D E F G
23. I have to ask people to repeat themselves in one-on-one conversation in a quiet room.	A B C D E F G	A B C D E F G
24. I have trouble understanding others when an air conditioner or fan is on.	A B C D E F G	A B C D E F G

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Comments: _____

Appendix C: Consent Form for Participants

University of Canterbury
Department of Communication Disorders
Private Bag 4800
Christchurch 8140



Are adults with hearing loss also at risk of attention and memory challenges, and can hearing loss intervention improve these cognitive areas?"

Consent Form for Participants

I have been given a full explanation of this project and have had the chance to ask questions.

I understand what is required of me if I agree to take part in the research.

I understand that participation is voluntary and I may withdraw at any time, without providing a reason. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain possible.

I understand that any information or opinions I provide will be kept confidential to the researcher Karyn Batchelor and the researcher's supervisor Dr. Kim Wise and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the University of Canterbury Library.

I understand that all paper data collected for the study will be kept in locked and secure facilities and all electronic data will be protected by passwords. All data will be destroyed after five years.

I understand the risks which occur by taking part and how they will be managed.

I understand that I am able to receive a report of the findings of the study by ticking the box below.

I understand that I can contact the researcher Karyn Batchelor at karyn.batchelor@pg.canterbury.ac.nz or the supervisor Dr Kim Wise at kimberly.wise@canterbury.ac.nz for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch or human-ethics@canterbury.ac.nz (Project Reference Code HEC 2015/34/LR)

Please tick a box below to indicate if you wish to receive a copy of the final report.

☐ Yes, please send me a copy of the final report.

☐ No, I do not want a copy of the final report.

By signing below, I agree to participate in this research project.

Name: _____

Signature: _____

Date: _____

Appendix D: Consent from McAuliffe and Sinex Project

**UC Speech Lab
Database
Request for Access**



Te Kāhui Roro Reo • New Zealand Institute of
Language Brain & Behaviour

Date: 28th May 2015

Name: Karyn Batchelor

Email: karyn.batchelor@pg.canterbury.ac.nz

Supervisor: Kim Wise kimberly.wise@canterbury.ac.nz

Department: Communication Disorders

Title of project: Are adults with hearing loss also at risk of attention and memory challenges, and can hearing loss intervention improve these cognitive areas?

Ethics approval (Include number and date): Not yet obtained

Database search

Age range: 60-90

Gender: Any

Other: Hearing loss which is typical of their age; age-related hearing loss (prebycusis)

Signed: _____

[Handwritten signature of M. McAuliffe]
M. McAuliffe

Supervisor signature: _____

[Handwritten signature of Kim Wise]
KIM WISE

Approved ☐

Declined ☐

*(approval contingent upon
ethics clearance of project)*